

FINAL REPORT OF PHASE II

HIGH SHOCK FM TRANSMITTER

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SECTION 1

INTRODUCTION

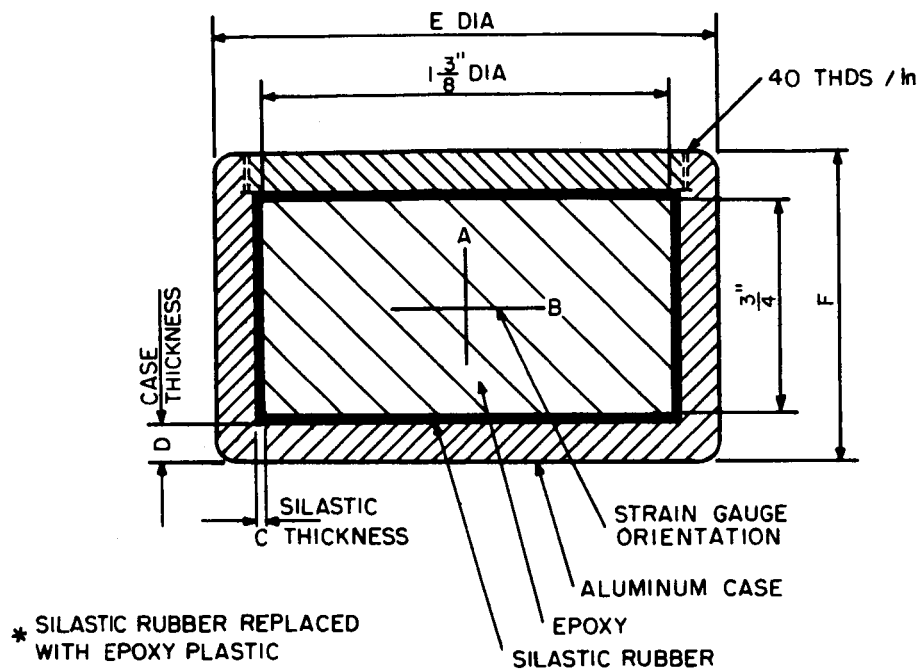
1 This report, the final report of the Phase II portion of the High Shock FM Transmitter project (No. NAS1-5042) describes the work completed during this phase.

2 The test results obtained from both the Phase II prototype transmitter and the final Phase II transmitters are tabulated and described for both the electrical and shock tests.

3 In addition to this, descriptions of the final case design, the transmitter circuit, the temperature compensating capacitor tests, and the compressed air launcher tests carried out using strain gauge test spheres, are given.

4 A brief resume of the electrical and impact tests conducted on the final Phase II transmitter is also included. Appendix A gives the electrical, vibration and shock specification as given in the program work statement. This has been included to provide a convenient reference to the design objectives of the High Shock FM Transmitter.

5 The conclusion at the end of this report briefly summarizes the important electrical and impact test results.



CONFIGURATION NO.	DIMENSION "D" (CASE THICKNESS) INCHES	DIMENSION "C" (SILASTIC THICKNESS) INCHES	CASE DIMENSIONS INCHES	
			E	F
4A	$\frac{1}{8}$	$\frac{1}{16}$	$1\frac{3}{4}$	$1\frac{1}{8}$
5A	$\frac{1}{8}$	$\frac{1}{32}$	$1\frac{11}{16}$	$1\frac{1}{16}$
6A	$\frac{1}{8}$	$\frac{1}{64}$	$1\frac{21}{32}$	$1\frac{1}{32}$
4B	$\frac{1}{16}$	$\frac{1}{16}$	$1\frac{5}{8}$	1
5B	$\frac{1}{16}$	$\frac{1}{32}$	$1\frac{9}{16}$	$1\frac{15}{16}$
6C	$\frac{1}{16}$	NO SILASTIC *	$1\frac{17}{32}$	$1\frac{28}{32}$

Figure 1. Mechanical Evaluation of Double Wall Case Design

SECTION 2

MECHANICAL CASE DESIGN

STRESS RELIEF

1 Quantitative measurements on various transmitter case configurations were completed in Phase II of this project to determine the effectiveness of stress relief in the double walled case chosen for the High Shock FM Transmitter.

2 Deflection in the outer case, due to loading, must not be transferred to the transmitter. To prevent this transfer, a thin layer of low bulk modulus material (silastic rubber) is placed between the outer case and the encapsulated transmitter so that as the outer case deflects under load, very little stress is transmitted by the silastic rubber and the transmitter is therefore isolated from the stresses occurring in the outer ball during impact. The results of the final impact tests indicate that the deflection of the epoxy ball is relatively large.

3 The poor mechanical impedance match formed by the silastic-aluminum interface also prevents shock wave propagation into the transmitter. The silastic coating also permits the transmitter to move slightly during the impact. Since the relative movement of the ball and concrete during impact is also small, a slight reduction in the g's experienced by the transmitter is thus provided.

4 Three dummy transmitter cases were produced to evaluate the effectiveness of various silastic and outer transmitter case thicknesses. Two strain gauges were applied to a copper-clad fibreboard chassis similar to the actual transmitter chassis. The strain gauges were oriented perpendicular to each other; one parallel to the cylindrical or A-axis of the transmitter and the other parallel to a diameter. They were then potted in Stycast 1090 plastic and machined to 1 3/8 inch overall diameter by 3/4 inch in length. The addition of Dow Corning 501 silastic and high strength aluminum cases completed the test configurations. The dimensions of the test configurations used are given in Figure 1. Numbers 4A, 5A and 6A were tested and then machined to produce configurations 4B and 5B. After the initial tests on 6A the strain gauge module was removed and repotted with Stycast 1090 into the aluminum case, becoming 6C. The directions of the loads applied coincide with the direction of the potted strain gauges. The thin fibreboard chassis, to which the gauges were bonded, was assumed to carry negligible load. The results of these tests are shown in Figures 2, 3 and 4.

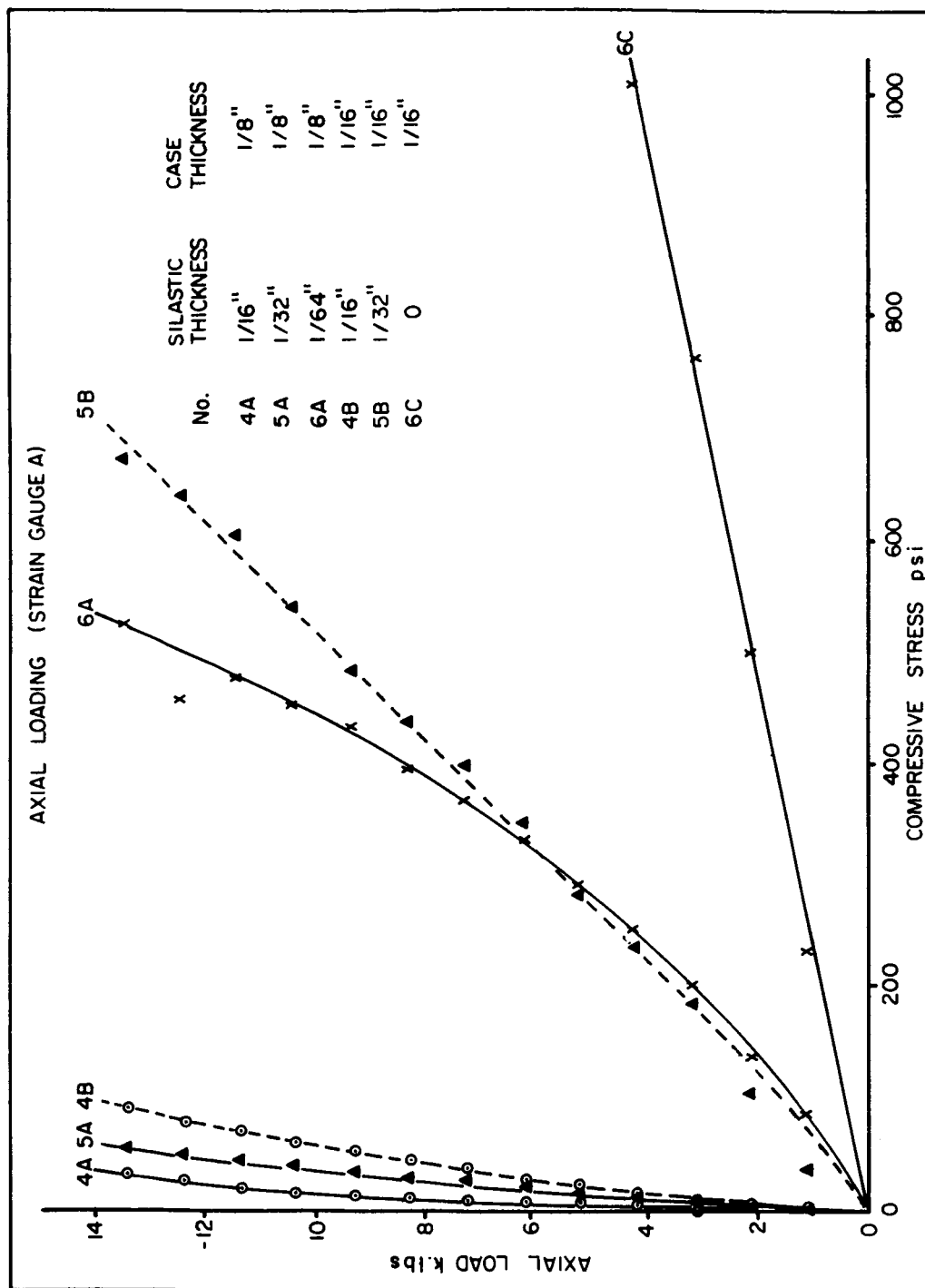


Figure 2. Compression Test Results on Double Wall Transmitter Case

Figure 2.

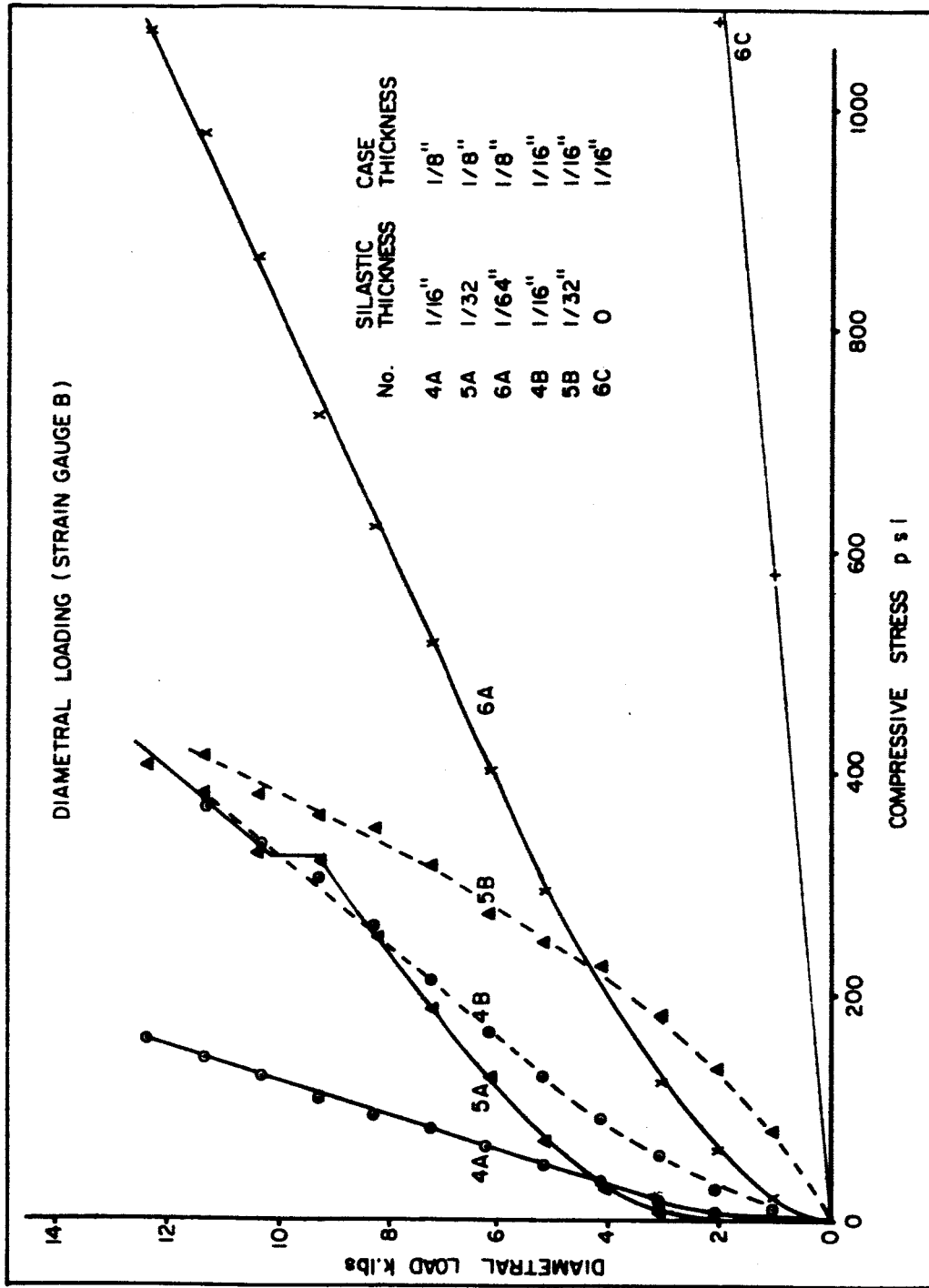


Figure 3. Compression Test Results on Double Wall Transmitter Case

Figure 3.

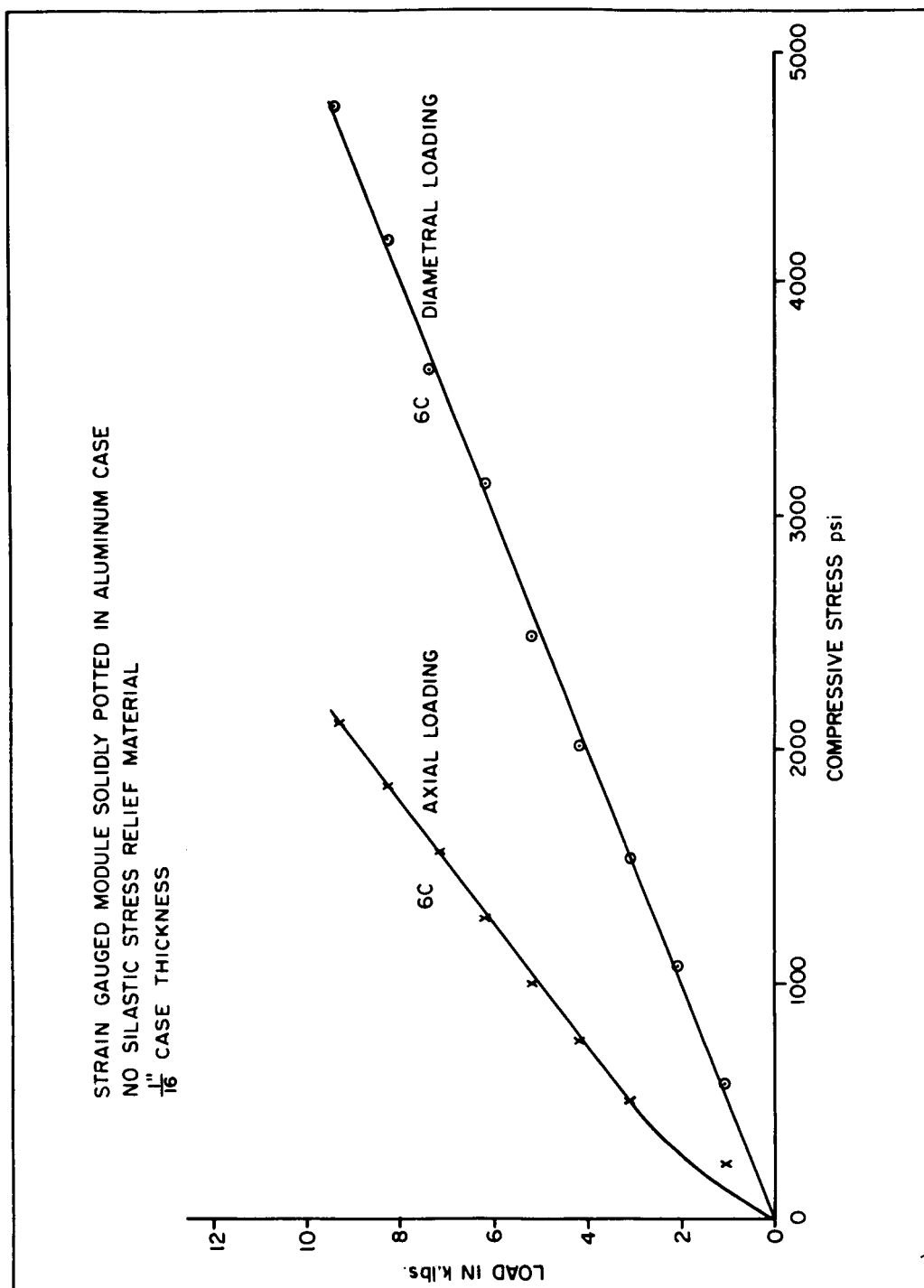


Figure 4.

Figure 4. Compression Test Results on Double Wall Transmitter Case

5 A large reduction in stress due to the stress relieving material is evident when these results are compared with those obtained from the solidly potted configuration 6C in Figures 2 and 3. The step in the 5A plot in Figure 3 was due to a change in the loading rate. As the load on the unit was held constant, the internal compressive stress relaxed. The loading rates on all other tests were held as constant as possible.

6 When the 1/16 inch thick cases were loaded parallel to a diameter, buckling of the ends was observed. As the ends would be supported laterally when in the fibreglass test ball, this mode of failure should be eliminated. Thus there should be less difference between the 1/6 inch case and 1/8 inch case in the ball, than is indicated by the compression test. The 5B unit was encapsulated into a 3.5 inch reinforced epoxy ball. Dynamic strain in the dummy transmitter during impact on the concrete target was measured and the results are indicated in a later section.

7 Compression tests on two of the above configurations were conducted using the Phase II prototype transmitter. The first case was similar to configuration 5B and, as seen in Figure 5, a maximum frequency shift of -45 kHz was observed when the case was diametrically loaded to 5000 pounds and +62 kHz when loaded axially with the same load. The load was limited to 5000 pounds because the case began to fail by buckling at its ends. The transmitter was then removed from the 1/16 inch thick case and repotted into a 1/8 inch case with a 1/32 inch thickness of silastic. This configuration is similar to 5A in Figures 2 and 3. Compression tests on this unit are shown in Figure 6 and indicate a maximum frequency shift of +18 kHz and -18 kHz for a 10,000 pound load in the diametrical and axial directions respectively. As mentioned earlier the 1/16 inch thick case was likely to show greater changes than the 1/8 inch because of buckling of the unsupported walls.

RADIO FREQUENCY SHIELDING

8 The use of stress relief between the inner transmitter module and the aluminum outer case requires that the transmitter module be well shielded to prevent relative movement of the two from affecting the transmitter frequency. The r.f. shield should only be as thick as necessary to provide good shielding and be well bonded to the plastic transmitter module. Three methods of forming the r.f. shield were investigated.

9 METHOD 1. A solid case made of brass shim stock, into which the transmitter module is potted. This type of r.f. shield was used on the Phase II prototype transmitter but compression tests on the unit indicated that there were air bubbles trapped between the module and the shim stock

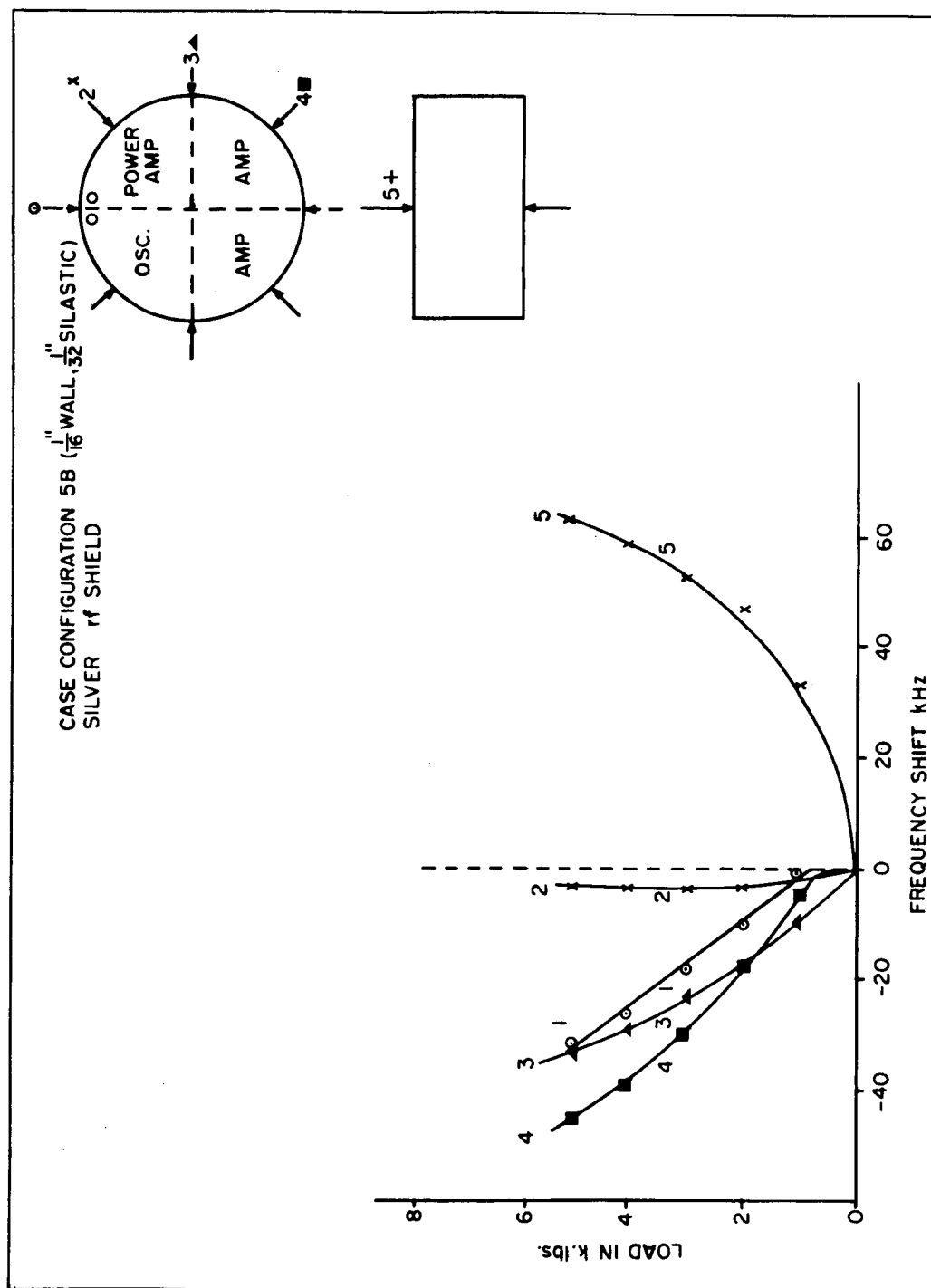


Figure 5. Compression Test Results on Phase II Prototype Transmitter

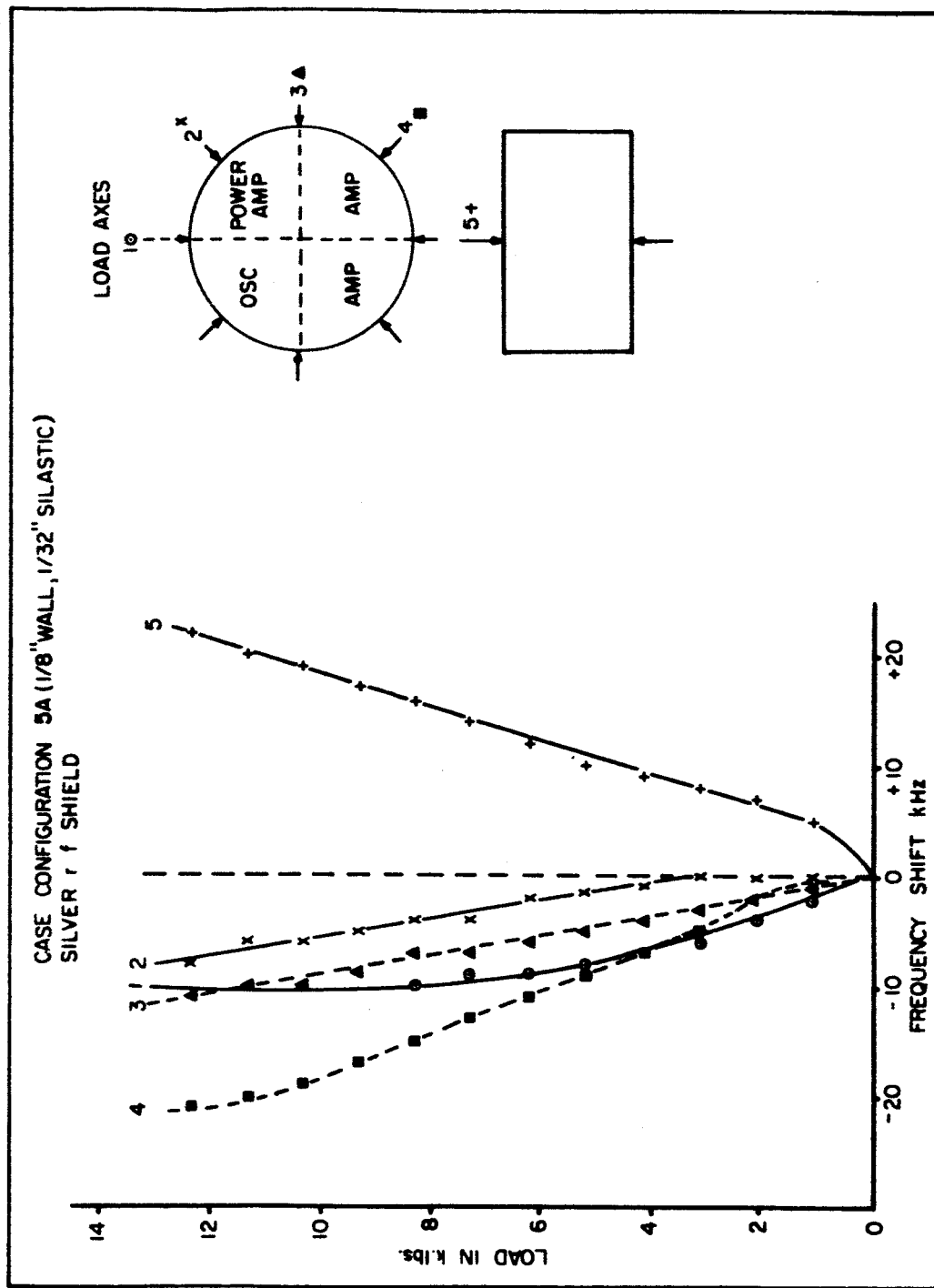


Figure 6.

Figure 6. Compression Test Results on Phase II Prototype Transmitter

case and when the loads were applied large changes in transmitter frequency occurred because of the flexing of the shim stock. More care in potting could probably overcome this problem but a further disadvantage exists with this shield in that it is difficult to make a good direct current connection between the transmitter chassis and the r.f. shield.

10 METHOD 2. A silver r.f. shield was applied to a test module first by applying a silver conducting surface using vacuum sputtering techniques and then electro plating 0.005 to 0.006 inches of silver. This method produced a very even layer of silver but it was found that the bond between the plastic and the vaporized silver layer was poor and the silver layer could easily be peeled away from the plastic.

11 METHOD 3. The last approach makes use of the silver plating technique except that the initial conducting surface was produced by a conducting silver paint or epoxy. Three conducting materials were tested as follows:

(a) The first was a conducting silver paint, NO21-1, made by GC Electronics. This material worked well during the plating process and the Phase II prototype transmitter was shock tested with an r.f. shield made of this paint and approximately 0.005 inch of plated silver. When the transmitter was dismantled to determine the cause of failure it was found that the bond between the paint and silver had failed over a rather large area of the transmitter module.

(b) The second was a silver lacquer, Eccocoat CC-2, made by Emerson and Cuming, on which the silver plating failed to deposit during the plating operation.

(c) The third material tested was Eccobond Solder 56C (also made by Emerson and Cuming) with catalyst 11. The bond strength between the silver and the conducting epoxy was judged superior to the previous materials treated. This method was used on the final transmitters.

12 The use of epoxy allows a direct current electrical connection to be made between the r.f. shield and the chassis ground. This connection is made by cutting the transmitter potting plastic back along the edges of the copper-clad fibreglass board chassis at the points where grounding of the r.f. shield is desired. The exposed copper is then coated with the conducting epoxy. The silver r.f. shield is attached to the chassis ground through the conducting epoxy.

CASE DESIGN OF THE FINAL TRANSMITTERS

13 The final transmitters manufactured as part of this project have a case configuration similar to 4B described in paragraph 4. This configuration is used, rather than the 5A case successfully tested in the Phase II prototype transmitter, for the following reasons:

(a) Figures 2 and 3 indicate that there is little difference between the two configurations, in fact, with the ball preventing the case from buckling the 4B configuration is probably better.

(b) The loading on the transmitter due to its own weight during the deceleration is much larger than the loading exerted on it by the ball, so that as shown in Figures 2 and 3, the small additional load applied to the transmitter by changing from the 5A case configuration to the 4B one is small compared to the overall load applied to the transmitter.

(c) A small additional reduction in the g's experienced by the transmitter will result by using the thicker silastic.

(d) The overall case size will be smaller, being 1-5/8 inches overall diameter by 1 inch in length. This size is a slight departure from the 4B configuration in that the ends of the outer case are 5/64 inches thick rather than 1/16 inch. The compression tests described in paragraph 7 show that axial loads produce the largest changes in frequency. The added thickness in the top and bottom of the final cases contributes to the stability of the transmitter.

14 A further improvement to the case design was considered. This involved the use of a chassis, similar to the Phase I prototype transmitter, which would help support the weight of the plastic and thus reduce the loading on each compartment in the transmitter.

15 The first design was to protect the oscillator section with an L-shaped section cantilevered to a rigid base. The chassis and wall would be made of aluminum. Such a design, it was felt, would limit the loading on the oscillator to the encapsulation plastic of this section alone. However, it was found that sufficient section modulus in the aluminum wall could not be obtained to significantly reduce the stress without going to a rather thick section which would increase the overall package diameter. No reduction in the size of the electronic module was possible. A further complication of the L section was that tensile stresses would be introduced into the transmitter module whereas before only compressive loads were present.

16 An X-shaped section was next considered but here again no appreciable

improvement is possible without considerable increase in size. Because of these calculations it was decided to retain the thin fibreboard chassis.

SECTION 3

PRELIMINARY TRIALS OF THE COMPRESSED AIR LAUNCHER

COMPRESSED AIR LAUNCHER

1 The general layout of Computing Devices' compressed air launcher is shown in Figure 7. The unit was originally mounted vertically as described in the Phase 1 final report but was moved to a heated building when space became available and is now mounted horizontally.

2 The gun is operated by admitting compressed air into the chamber formed by the breech of the gun and the sabot. The sabot is released manually with a mechanical release mechanism. The ball and sabot are accelerated to the end of a five foot barrel where the sabot is separated from the ball with a sabot plate and expendable styrofoam ring.

3 The target is held at an angle of 70 degrees to the line of flight and the ball is rebounded into a box containing packing material. The target is a 12 X 12 X 6 inch reinforced 6,000 pound test concrete block, which is held in a heavy angle-iron frame. The position of the block may be moved to provide a fresh contact area for each impact.

4 The velocity of the ball is measured by two break-wire stations one foot apart. To obtain a trigger for initiating oscilloscope sweeps just before impact, a simple broken-beam light screen detector has been mounted one half inch in front of the target.

5 Cables between the instrumentation and the ball are required to provide power to the ball. These 'trailing wires' are a twisted pair of Number 22 braided teflon hook-up wires. These cables have proven to be satisfactory for this application if replaced frequently.

ACCELEROMETER AND STRAIN GAUGE MEASUREMENTS

6 Attempts to make accelerometer and strain gauge measurements in the ball as it impacted on the concrete target were not highly successful because of difficulties with the Microdot coaxial cable used.

7 Readings from the strain gauges mounted in the 5B configuration case indicate an impact deceleration time of 0.21 milliseconds. This is considerably shorter than the 1.03 millisecond pulse calculated in Phase 1 of this program and indicates higher g's loading than anticipated. The

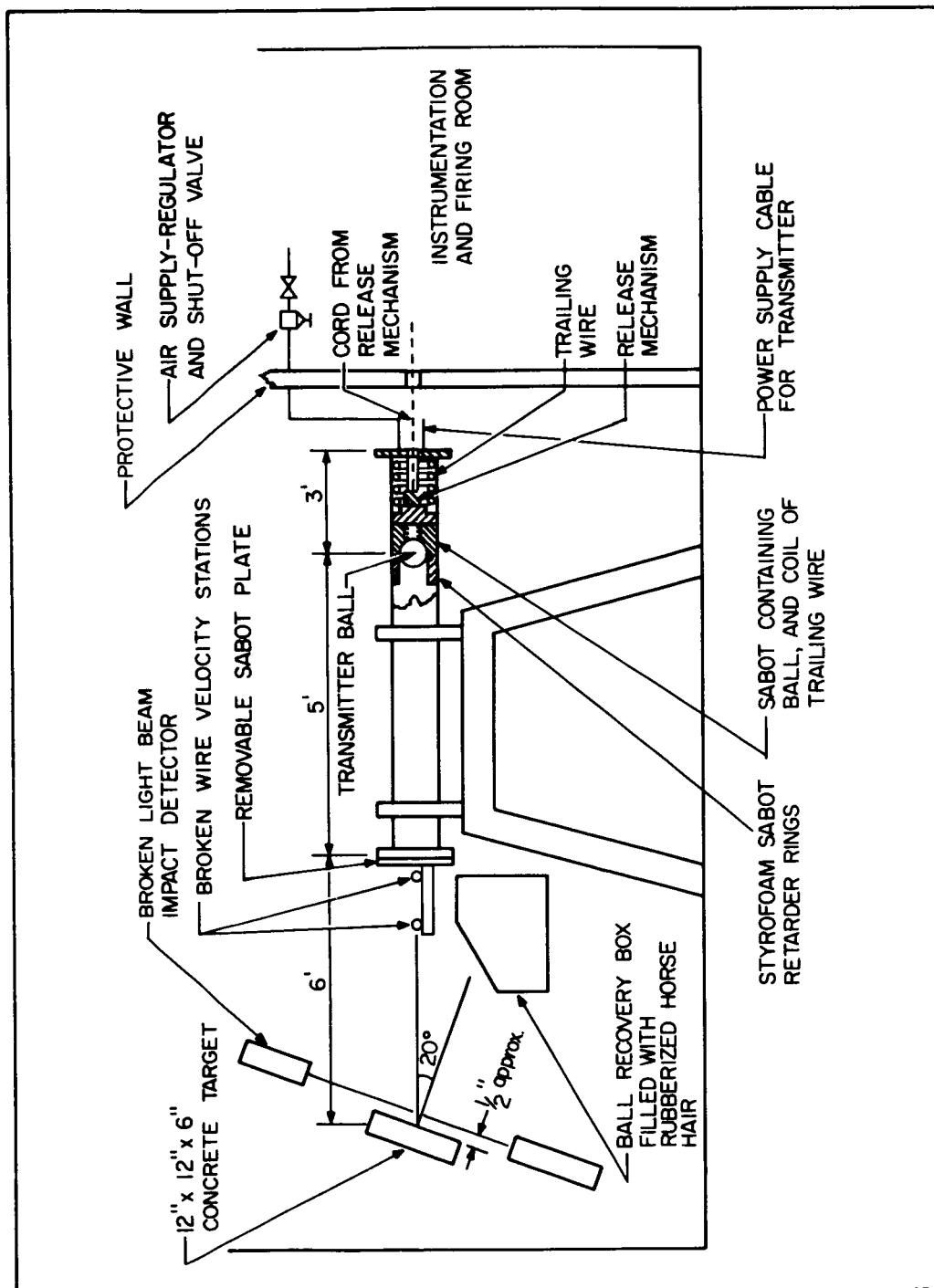


Figure 7.

Figure 7. Computing Devices' Compressed Air Launcher

calculations of pulse time and g's loading were based on the Hertz contact laws which are highly dependent on the elastic constants of the impacting objects. The constants of elasticity for the ball are difficult to evaluate as they are dependent on loading rates, and method of application and quantity of the fibreglass reinforcement.

8 Since the same constants of elasticity appear in both the contact duration and the maximum acceleration formulae, the deceleration can be calculated accurately knowing the impact duration. The calculated value for an impact velocity of 110 feet per second and a pulse duration of 0.21 milliseconds is 60,000 g's.

9 This acceleration should produce a maximum stress of 1,800 pounds per square inch in the package. However, the strain measurement in the ball indicated a stress of 2,800 pounds per square inch for an impact velocity of 110 feet per second. This discrepancy was not resolved, but the overall pulse duration measurement has proven to be accurate from tests conducted on the final transmitters.

10 Correlation between the strain gauge record and the compression and impact tests on the prototype transmitter was also poor. The small frequency changes exhibited by the transmitter during the impact test indicate a much smaller stress in the transmitter than shown by the strain gauge record. The number of usable strain gauge records obtained was again limited by the cable failure.

HIGH SPEED IMPACT PHOTOGRAPHS

11 A high framing-rate camera (Fastax) was used to make in-flight photographs of the ball and trailing wires. The sequence shown in Figure 8 was taken from one of the filmings. The framing rate was 7,680 frames per second and projectile velocity was 113 feet per second. Two mirrors were used to improve the information content of the pictures. The first mirror, just to the right of the target was adjusted so that the ball was viewed at right angles to its trajectory as it impacted on the target. The thin white line in this mirror represents the entire surface of the target. To the right of the first mirror is a second mirror which provides a view of the gun muzzle.

12 The photographs confirm the short impact time measured by the strain gauges. The ball appears to be in contact with the target for less than 0.5 milliseconds. A dimension change across the diameter of the ball parallel to the surface of the target is difficult to detect.

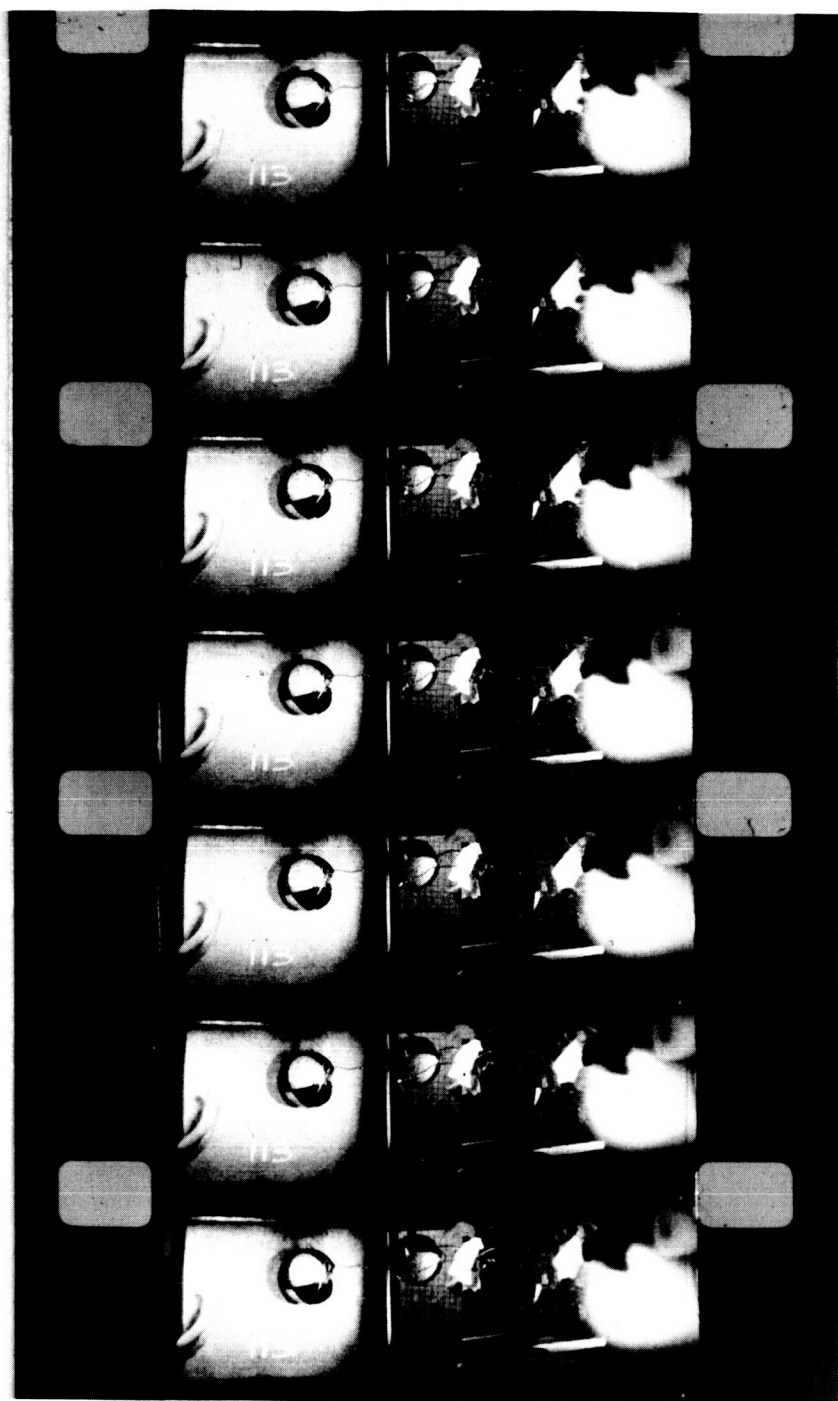


Figure 8. Fastax Photograph Showing Impact of Test Sphere into Concrete Target

IMPACT TESTS ON PHASE II PROTOTYPE TRANSMITTER

13 The Phase II prototype transmitter was impact tested using the 5A case configuration. Of the twenty test shots fired only six usable records were obtained and only two of these were considered good.

14 The results of the impact tests on the Phase II prototype are shown in Table 1 below:

Compressed Air Launcher Shot No.	ΔF kHz	Velocity ft/sec	Remarks
119	-88	110	Impact point approx. 45° off A-axis *
121	-38	125	
127	-29	135	Poor record, cable broke during impact
130	+11	131	
131	-58	160	Poor record, r.f. filter capacitor failed
132	-18	128	Poor record, r.f. filter capacitor failed
* The A-axis is the cylindrical axis of the transmitter case. Although diametrical axes were also used, most of the impacts occurred along the A-axis because of ball rotation between the sabot and target.			

Table 1. Impact Tests on the Phase II Prototype

15 The two problems which prevented reliable data from being obtained were cable breakages and r.f. feedback into the transmitter through the trailing power cable. The latter problem was overcome by adding an r.f. filter at the cable connection of the ball, but repeated failure of the unsupported components on the surface necessitated the encapsulation of the filter into the ball. Even then the components, particularly the capacitor, failed during each shot. This filter has been incorporated into the final transmitter design and no further difficulties of this nature should be encountered. Cable breakage was virtually eliminated by frequent cable changes.

16 Variations in signal strength were also detected on some of the shots. The exact reason for these variations was not determined but it was felt that the changes which did occur were not due to power output changes. As all the shots were not affected it appeared to be due to standing waves in the air gun structure. The possible effect of the transmitter approaching the steel reinforced concrete target and steel target support structure may have caused the changes. The transmitter antenna was a four inch length of buss wire embedded one half inch below the surface of the ball. A similar transmitter antenna was used for the final transmitter except that the antenna cable was terminated with a 50 ohm resistor.

17 A mechanical failure, probably an open connection in the feedback circuit in the oscillator of the Phase II prototype transmitter, terminated the tests after twenty shots.

SECTION 4

TRANSMITTER COMPONENTS

TEMPERATURE COMPENSATING CAPACITORS

1 At the completion of Phase I the need for a temperature compensating capacitor suitable for the High Shock FM Transmitter was apparent. Considerable effort was expended during Phase II to find a suitable device.

2 Initial tests on the pendulum tester indicated that both the tubular type and the disc type of capacitors were acceptable, although the changes for a given stress level were an order of magnitude greater than the Vitramon or Corning capacitors tested earlier.

3 A number of tests were carried out on the compression tester comparing various capacitors while operating at r.f. frequencies. The components under test, see Figures 9, 10, 11 and 12, were encapsulated in one inch cubes of Stycast 1090 (Cat. No. 11) plastic and subjected to various loads in the compression tester. Great care was taken to provide adequate shielding and to minimize relative movement between the test components and the exciting circuits. Figure 9 gives the result of tests made on a tank circuit comprising an alumina coil and a Corning CY10C capacitor. The various orientations of the components with respect to the axis of the load are depicted in the small diagrams in Figure 9. The results indicate that configurations 3 and 4 are superior and these components are oriented in this configuration with respect to the grounded r.f. shield in the final transmitters.

4 Figure 10 gives the results obtained using a similar coil but with the Erie type 301 (N750) tubular temperature compensating capacitors. Large changes in frequency occurred. These capacitors were used in the Phase II prototype transmitter and may account for some of the frequency shift. Figure 11 shows the results obtained using Erie disc capacitors. These units are considerably better. Comparing Figures 9 and 11 it is seen that the frequency change for the disc capacitor is of opposite sign to that of the Corning unit. Figure 12 gives the results of the alumina coil alone.

5 The data obtained from these compression tests are considered quite accurate. The main source of error is due to sample movements because of uneven loading.

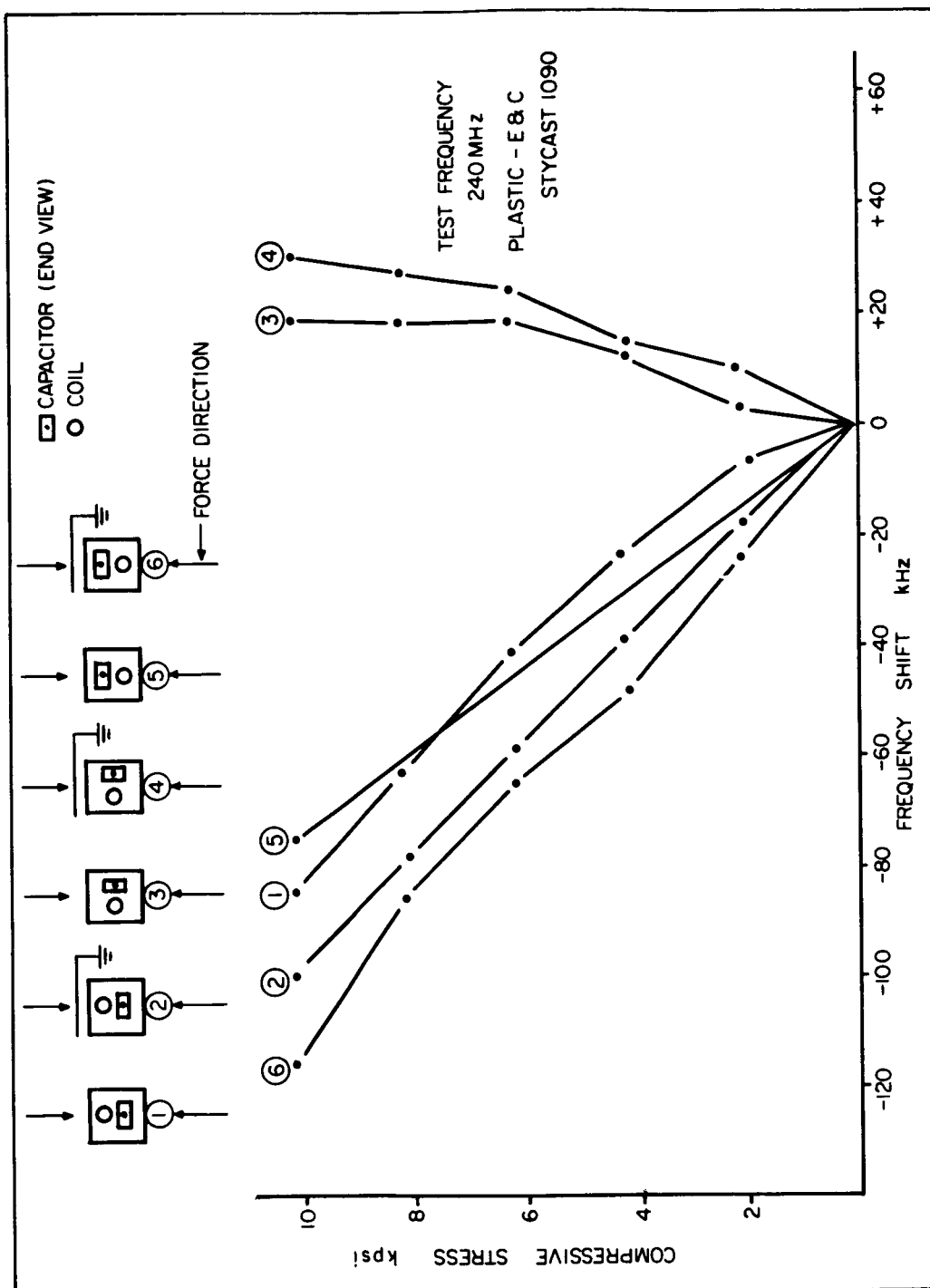


Figure 9. Compression Tests on R.F. Components

Figure 9.

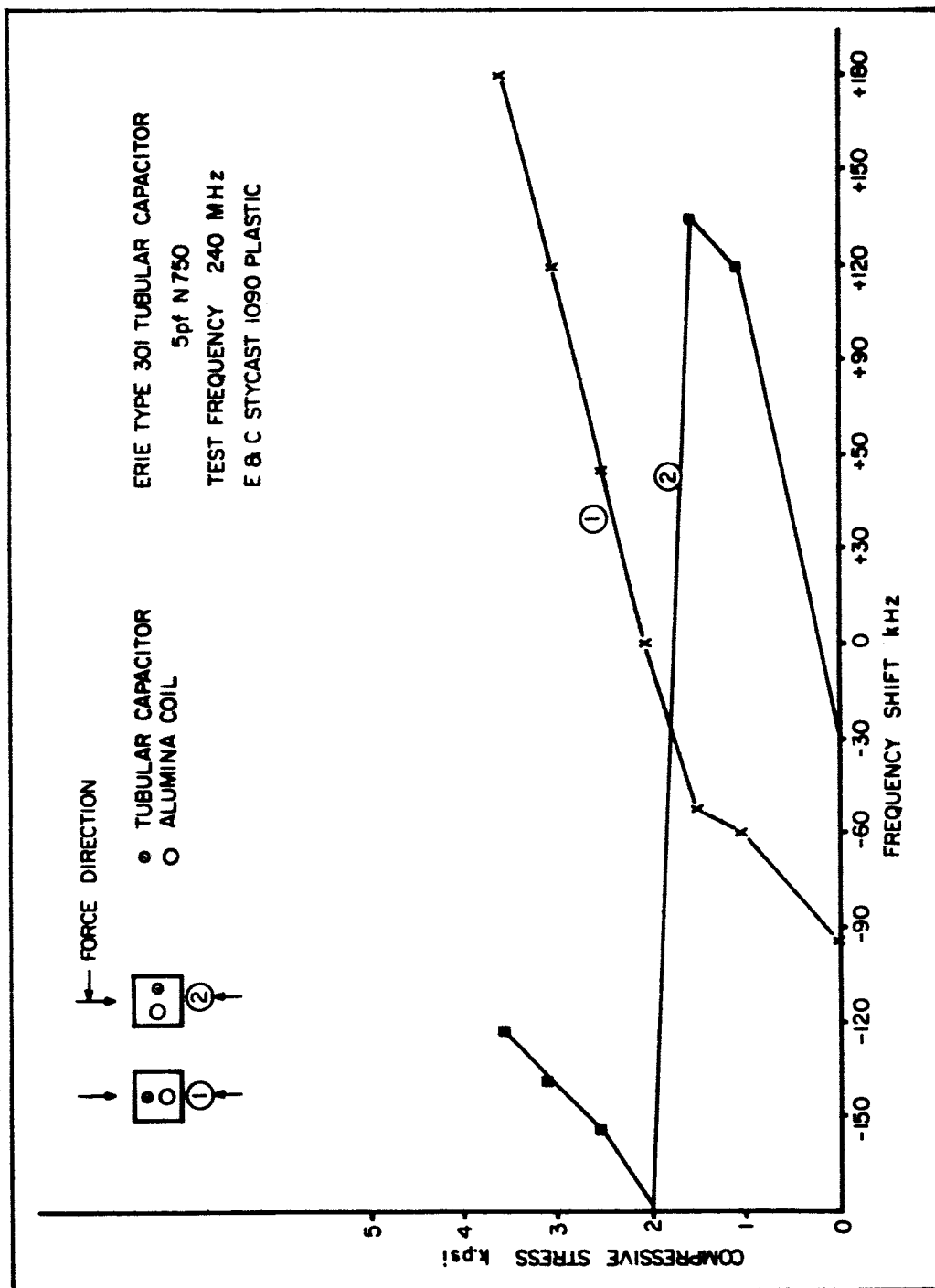


Figure 10. Compression Tests on R.F. Components

Figure 10.

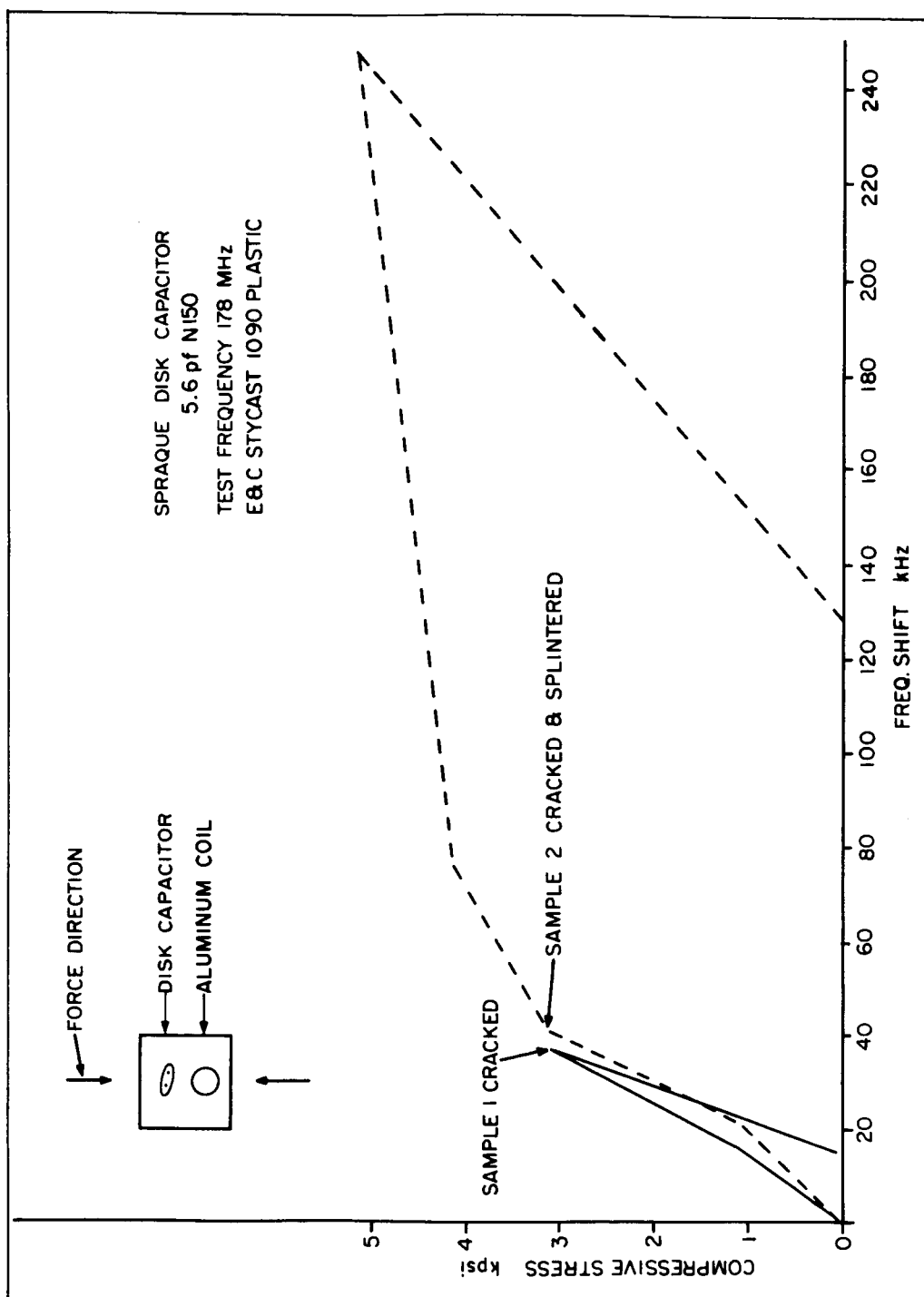


Figure 11. Compression Tests on R.F. Components

Figure 11.

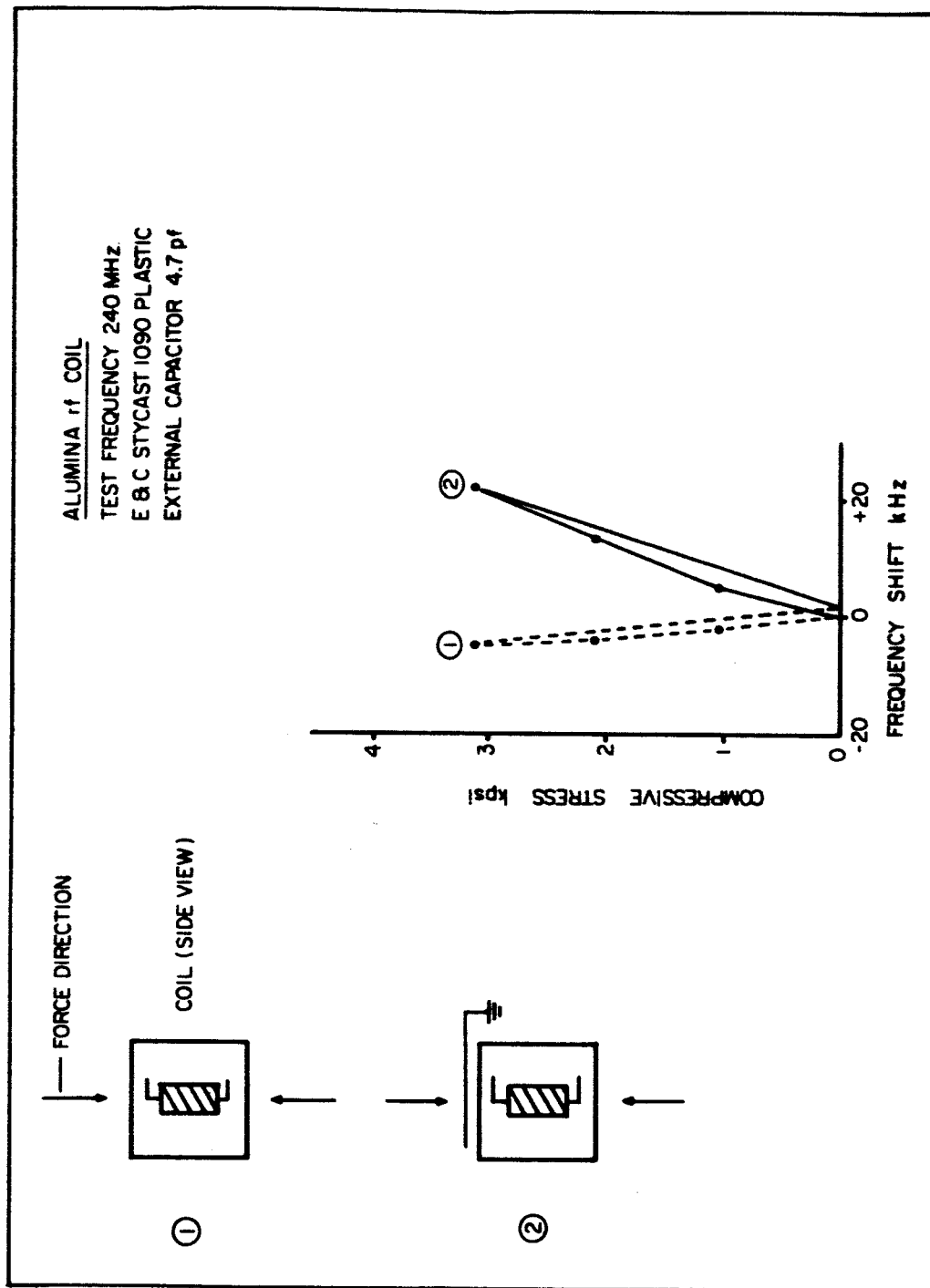


Figure 12. Compression Tests on R.F. Components

Figure 12.

TRIMMER CAPACITORS

6 One of the major problems in the design of the High Shock FM Transmitters has been the lack of trimmer capacitors which can be adjusted after potting. The effects of potting on the transmitter are not completely understood and it has been found difficult to predict completely what will happen to a particular circuit when it is potted.

7 Several types of trimmer capacitors were considered but none were considered completely satisfactory. A movable slug in a tubular capacitor which is potted in place after the final frequency adjustment is one possible type. Another, is a tubular capacitor with a slug of soft solder. The capacitance is adjusted by changing the level of the solder with a soldering iron. Both methods show some promise but are not too convenient and may have undesirable side effects such as deterioration of the supporting plastic due to heating in the latter unit.

8 The final transmitters were trimmed using two series capacitors shunting the r.f. coils. The first capacitor is the temperature compensating capacitor and is made somewhat larger than that required to trim the circuit. This capacitor is potted during the first potting operation on the transmitter. A Vitramon or Corning capacitor is used to make the final frequency adjustments.

9 Difficulty was experienced with the N750 disc capacitors during the initial stages of assembly. It was found that the bond between the lead wires and the dielectric material was very weak. To overcome this problem the discs were re-silvered using the Hanovia Liquid Silver No. 467 in a manner similar to the r.f. coils described below, but at a lower temperature 600 degrees Celsius. Electrical tests were carried out on these modified capacitors to determine if any changes in their temperature coefficient had occurred. It was found that a small reduction in temperature coefficient had occurred, but not sufficient to prevent them from being used in the transmitter. These modified disc capacitors are used in all the tuned circuits of the final transmitters and as a filter capacitor at the power input connection.

RADIO FREQUENCY COILS

10 The r.f. coils used in the final transmitters are essentially the same as the units described in the Phase I final report. The only deviations are in the size, which has been changed to a quarter inch in diameter by 5/16 inch in length, and in the silvering, which is applied in very thin layers. The first change has provided a more rugged coil of a size more convenient

for the available transmitter space. The additional layers of silver increased the average Q of the coils to greater than 140 at 200 MHz.

POWER TRANSISTOR

11 Several failures in the power transistors during the assembly of the various transmitters built in this project has required that the power transistors not be potted. The failures occurred only in potted transistors and appeared to be due to the fine internal wires breaking during the temperature tests on the transmitter.

12 To overcome this problem a small brass cap has been designed to fit over the 2N3066 after most of its case has been removed. The cap is soldered to the base of the transistor to prevent cleaning solvents from leaking into the transistor during the pre-potting cleaning step in the assembly procedure. The completed unit is then soldered directly to the top of the r.f. coil.

SECTION 5

TRANSMITTER CIRCUIT DESCRIPTION

GENERAL

1 The High Shock FM Transmitter described in this report attempts to combine the advantages of simple electrical and mechanical design into a transmitter which is easy to build and tune and which meets the program's electrical and shock specifications.

2 The transmitter uses a Colpitts oscillator to eliminate the need for a tapped r.f. coil, and grounded emitter amplifier stages are used for maximum stability. Frequency stability is improved by using a regulated power supply for the oscillator and first amplifier, and by operating the oscillator and first amplifier at a very low power level. Operating at low power levels also keeps the overall transmitter efficiency high. To overcome the lack of suitable high shock trimmer capacitors, two capacitors, one with a negative and the other with a positive temperature coefficient, are used to tune the various stages and provide temperature compensation. Exact temperature compensation is difficult to achieve because of the changes in performance introduced by the plastic encapsulating material.

3 The transmitter circuit consists of five stages:

- (a) The D.C. bias circuit.
- (b) The oscillator.
- (c) The first buffer amplifier.
- (d) The second buffer amplifier.
- (e) The power amplifier (output).

4 Each stage is built into a separate compartment of the chassis to provide maximum r.f. shielding between stages. Decoupling at r.f. is provided on all supply lines. The circuit diagram and parts list are shown in Figures 13 and 14.

THE D.C. BIAS CIRCUIT

5 A constant D.C. supply is required for the oscillator and first amplifier stages to provide maximum isolation from power supply variations. The necessary regulation is provided by shunting these stages with a 5.5 volt zener diode, CR2. This diode is intrinsically temperature compensated by virtue of its construction.

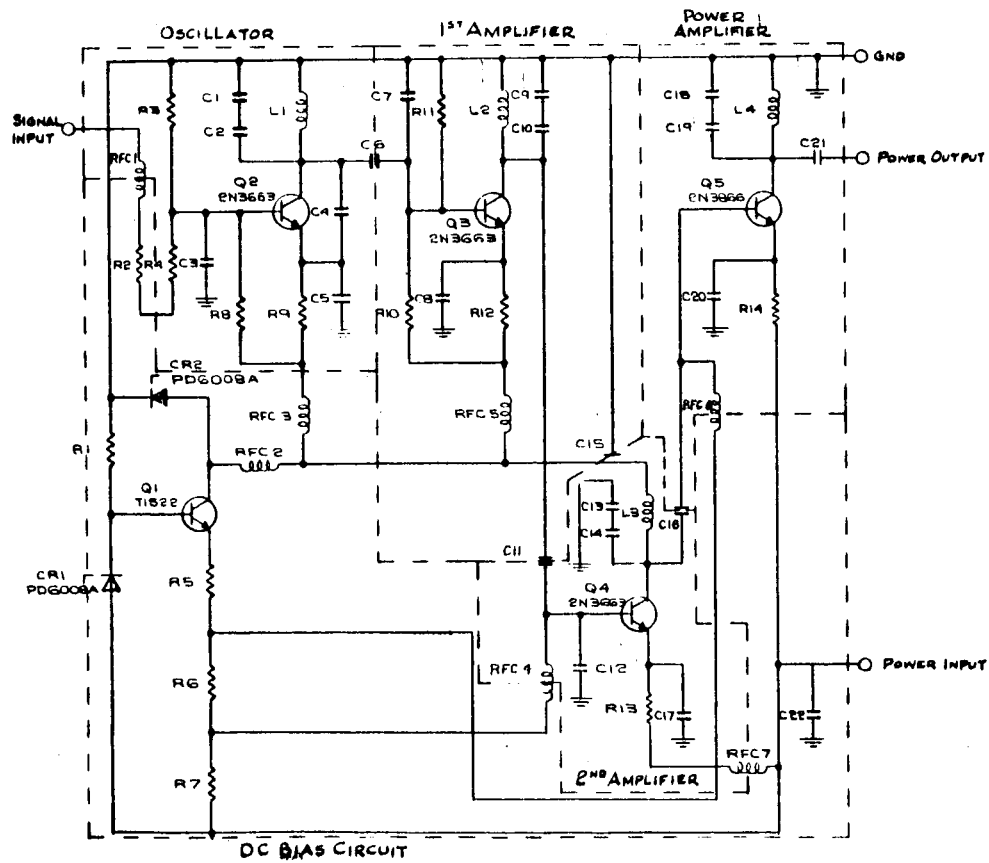


Figure 13. High Shock FM Transmitter Circuit Diagram

6 Current for CR2, the oscillator and the first amplifier is provided by Q1 and Q4. These are constant current sources because the base potential of Q1 is held at a constant 5.5 volts above the negative potential by the zener diode CR1. The constant emitter current of Q1 provides a constant voltage drop across R6 and R7 to provide a constant base potential for Q4 and the power amplifier transistor, Q5.

THE OSCILLATOR CIRCUIT

7 The oscillator is a Colpitts type using a 2N3663 in the common base mode. The combination of C4 and C5 provides current feedback into the emitter.

8 The oscillator is modulated by varying the base potential and hence the collector capacitance of Q2. The modulation sensitivity of the oscillator is adjusted by the modulator input resistors R2 and R4.

9 The input is D.C. coupled because of the lack of large value shock insensitive coupling capacitors. For this reason and because of the voltage divider formed by R2 and R4, the input is at a potential of approximately -4 volts.

10 The oscillator is tuned by the series capacitors C1 and C2. C2 is a temperature compensating capacitor. The oscillator is loosely coupled through C6 into the first amplifier. The oscillator output at this point is approximately half a milliwatt into a 50 ohm load.

THE FIRST AMPLIFIER

11 This circuit uses a common emitter configuration using a 2N3663. Tuning variations due to supply voltage fluctuations are limited by using a constant voltage source CR2. The first amplifier is tuned with series capacitors C9 and C10. Capacitor C10 has a negative temperature coefficient and provides the necessary temperature compensation.

12 The output from the first amplifier is coupled through C11 into the second amplifier. The power output through C11 is approximately two milliwatts into a 50 ohm load.

THE SECOND AMPLIFIER

13 This stage is similar to the first amplifier. The capacitor combination

of C11 and C12, together with the input capacitance of the transistor Q4, provide an impedance transformation which can be adjusted for optimum gain as required. Although the voltage across this stage may vary from 11 to 19 (supply voltage -20 ± 4 volts) the tuning of the oscillator is not effected because of the buffering provided by the first amplifier. The power output from the second amplifier through C16 is 10 to 20 milliwatts into a 50 ohm load.

THE POWER AMPLIFIER (OUTPUT)

14 A 2N3866 transistor is used in the power amplifier because of the large power dissipation which occurs in this stage. The circuit is similar to the one used in the previous two amplifiers. The minimum power output through C21 is 100 milliwatts into a 50 ohm load.

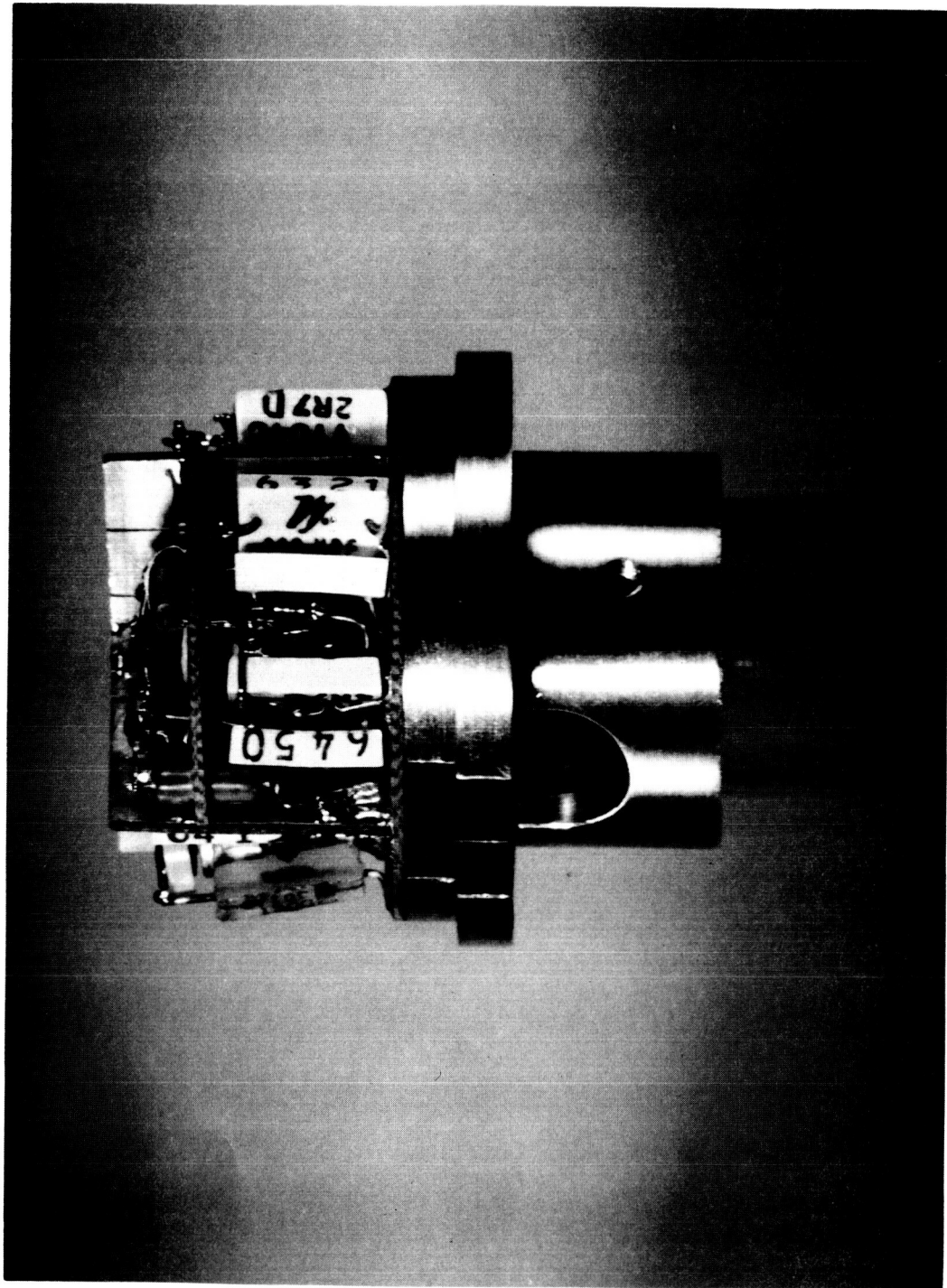


Figure 15. Photograph Showing Oscillator and D.C. Bias Circuit in Unpotted Transmitter

Figure 15.

SECTION 6

TRANSMITTER ASSEMBLY

GENERAL

1 The assembly of the High Shock FM Transmitter is detailed in the Engineering Report for this project. A brief description of some of the more important aspects of the assembly are given below.

COMPONENT LAYOUT

2 The layout of components was made on the basis of available space, radiofrequency and shock requirements. Because a chassis with structural members to support the bulk of the plastic was not possible (see Section 2, paragraph 13) care was taken during the layout of the final transmitters to place the components most sensitive to shock near the centre of the transmitter module. An example of this is the disc temperature compensation capacitor used in the oscillator. This unit is just visible in Figure 15 at the back of the oscillator compartment. The tests described in Section 4 indicate that the Vitramon capacitors should be mounted with their narrow edge next to the walls of the transmitter. Such an arrangement was used as seen in Figures 15, 16 and 17. The remainder of the components were located to provide the best r.f. layout in the smallest possible volume. Care was also taken to provide maximum decoupling between stages.

TRANSMITTER TUNING

3 The limited space and the effects of potting have proven to be the major problems in designing for maximum performance of the transmitters. The somewhat random variations which occur during potting and the unavailability of a simple adjustable trimmer capacitor has made it difficult to maintain the pre-potting electrical specifications.

4 To minimize these effects potting must be carried out in a series of steps. The first encapsulates all the components except the tuning capacitors in each stage and the modulation sensitivity resistor. Figure 18 shows the transmitter after the initial potting. The small cavities in the walls are for the tuning capacitors which will be added and potted in two further steps. First the oscillator and power amplifier and after readjustment for maximum transmitter performance, the 1st and 2nd amplifier tuning capacitors. The modulation sensitivity resistor is potted last.

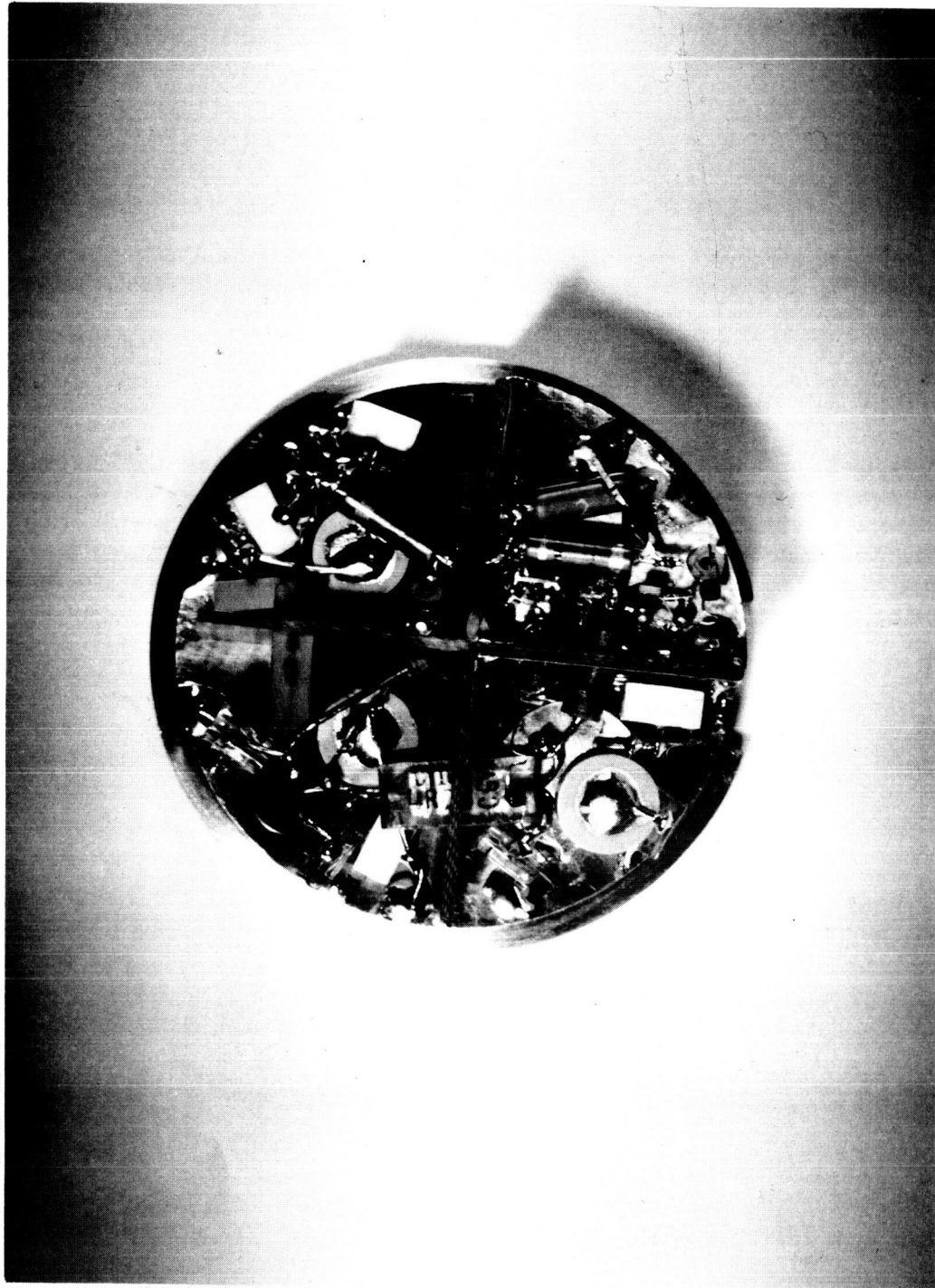


Figure 16. Photograph Showing Top View of Unpotted Transmitter

Figure 16.

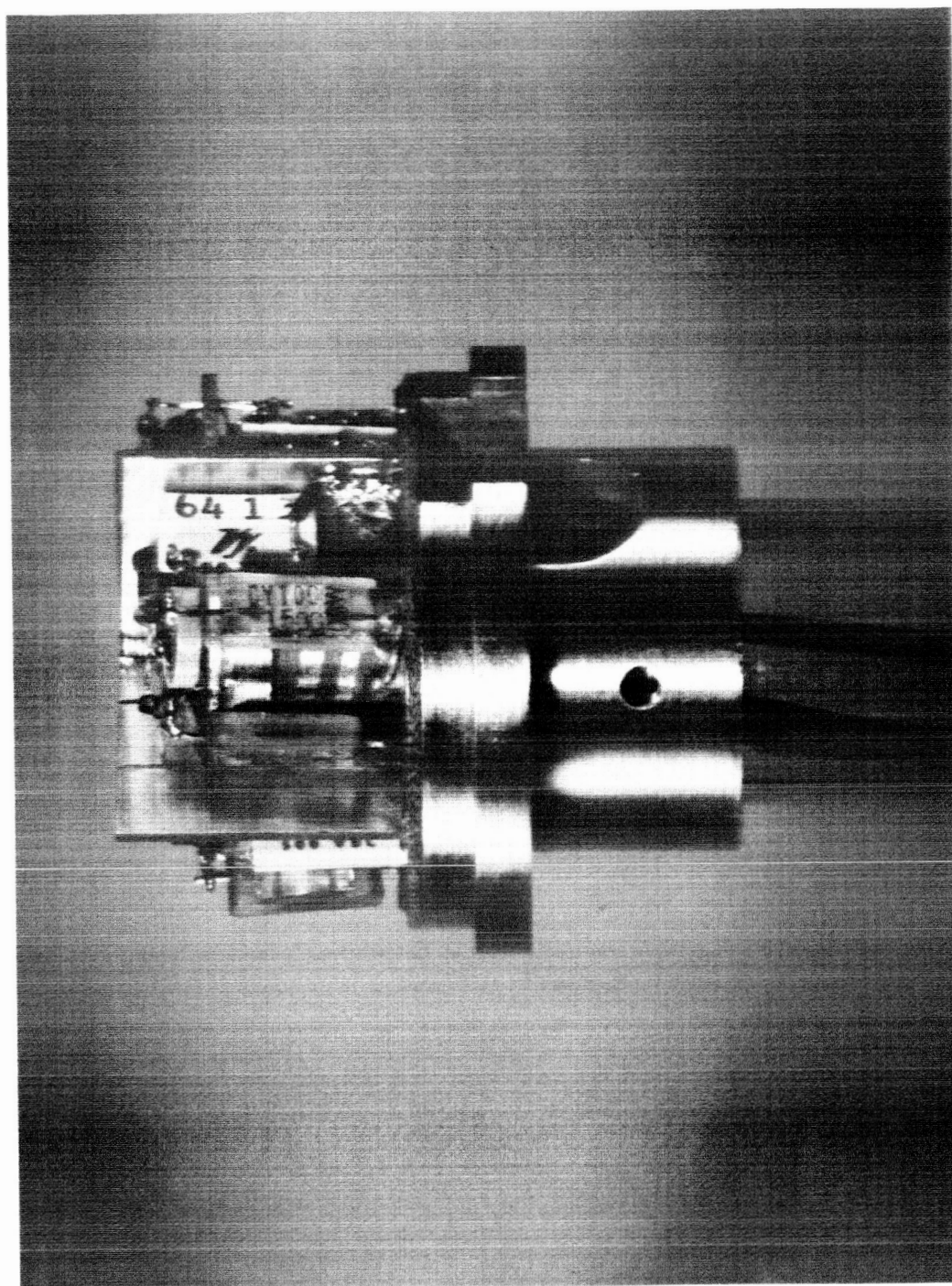


Figure 17. Photograph Showing Power Amplifier of Unpotted Transmitter

Figure 17.

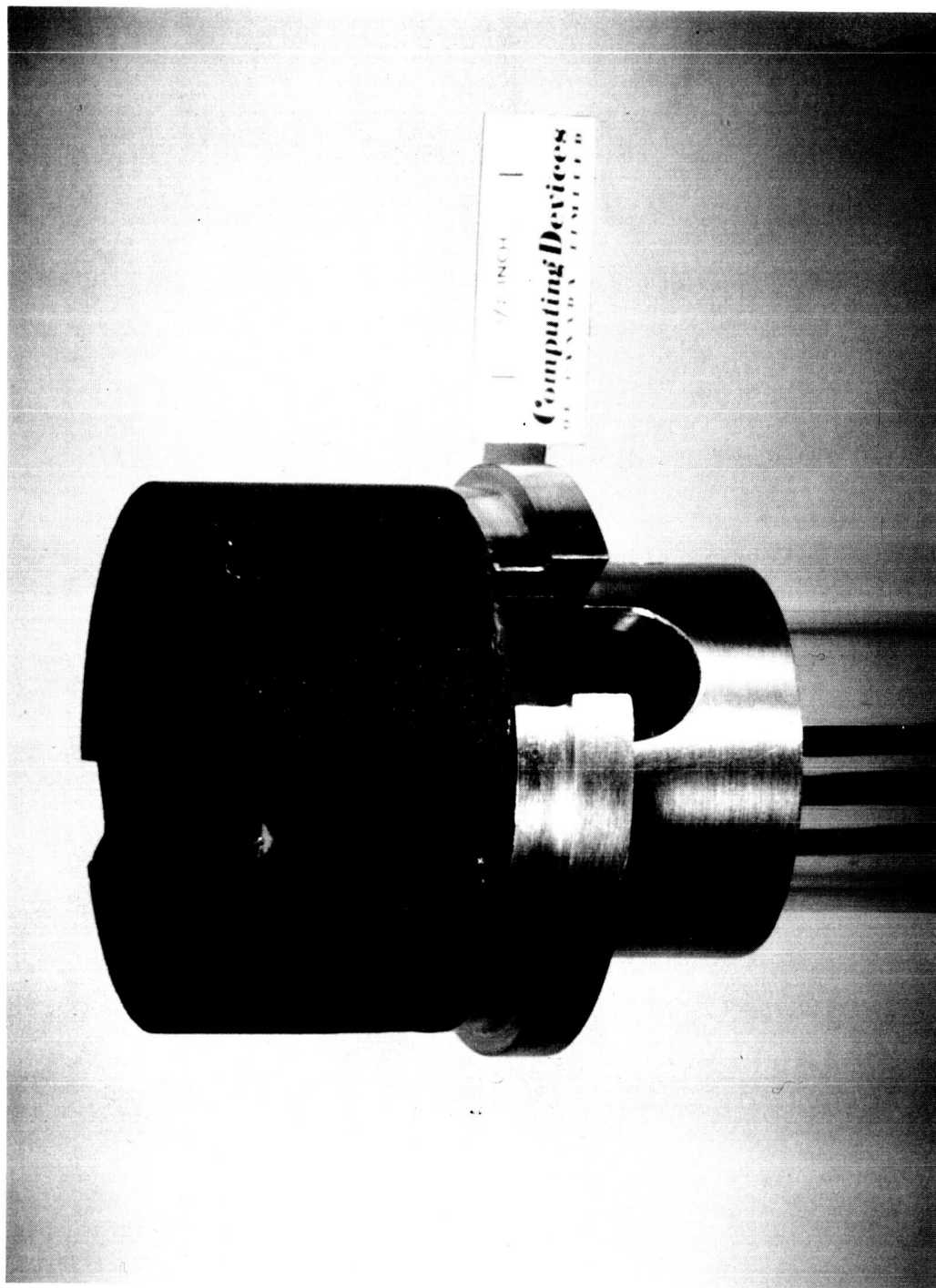


Figure 18. Photograph Showing Transmitter Module After First Potting

Figure 18.



Figure 19. Photograph Showing Transmitter Module with Silver R.F. Shield
and Rubber Spacers

Figure 19.



Figure 20. Photograph Showing Final Transmitter YTX-1-2

Figure 20.

FINAL ASSEMBLY

5 After potting, the r.f. shield is applied to the outer surface of the transmitter module as described in Section 2. The module is then potted into the outer aluminum case with silastic rubber, using narrow 1/16 inch rubber strips glued to the r.f. shield, as spacers to maintain the necessary distance between the module and the outer case. These spacers attached to the r.f. shield are shown in Figure 19. The completed transmitter YTX-1-2 is shown in Figure 20.



Figure 21. Photograph Showing Fiberglass Re-inforced Epoxy Test Sphere

Figure 21.

SECTION 7

TRANSMITTER TESTS

IMPACT TESTS

1 **BALL MANUFACTURE.** The transmitters were molded into 3.5 inch diameter fibreglass reinforced plastic balls for the impact tests in the following manner. To provide the minimum cable length (three inches) on the final transmitters after they have been removed from the test ball five or six inches of cable must be stored next to the transmitter case. To do this the cables are first wrapped with a thick layer of rubber tape and then coiled up and potted in a clear plastic module bonded to the end of the transmitter case. Such a procedure greatly simplifies the removal of the outer epoxy covering.

2 Fibreglass wool is used to form an initial ball shape around the transmitter of approximately 2.5 inches diameter. The initial form is then wrapped with fibreglass tape to form a uniformly packed ball of 3.5 inches diameter. The tape is tightly wound to provide maximum strength and durability. The density must be controlled to prevent potting problems.

3 The fibreglass ball is impregnated with RDD5* plastic in a 3.5 inch spherical mold and the complete ball is shown in Figure 21. The mold is made in such a way that the epoxy can be drawn through the fibreglass reinforcing material by vacuum techniques. Care should be taken to prevent the plastic from exotherming and hardening in the mold before the potting is complete. The power cable was brought to the surface of the fibreglass ball where approximately one inch of cable was stored in a small silastic plug. After potting, two solder terminals were mounted slightly below the surface of the ball and the power lead attached. The unused volume created by the silastic plug was filled with an epoxy plastic.

4 The antenna consisted of a two inch length of wire located between the fibreglass wool and the fibreglass tape, a 50 ohm Ceradot resistor is connected across the power output lead.

5 To determine the axis of the transmitter after encapsulation in the ball, X-Ray photographs were taken. Lead strips attached to the transmitter case were used to provide orientation. From the X-Ray photographs, the cylindrical axis and the orientation of the various sections of the transmitter were thus determined.

* RDD5 COMPOSITION CIBA EPOXY RESIN 991, 88 PARTS
 CIBA EPOXY RESIN 992, 28 PARTS
 CIBA DILUENT 996, 2 PARTS
 CIBA HARDENER 991, 12 PARTS

6 When each of the axes described below had been located, a hole was drilled and tapped into the ball to permit the installation of an anchor stud for the trailing wires used during the test program. The axes were designated as follows:

A-axis Along cylindrical axis of transmitter.

B-axis Diametrical axis through oscillator and second amplifier 45 degrees to transmitter partitions.

C-axis 90 degrees to A and B axes, through first amplifier and power amplifier.

7 The stud was located such that the impact points were as follows:

A-axis Base of transmitter (end at which cables leave case) is away from target.

B-axis Oscillator next to target.

C-axis First Amplifier next to target.

8 Although the ball is fired along specific axes, rotation of the ball between the sabot and the target provides a fairly random distribution of impacts over the surface of the ball. Because the impact print is approximately 1 1/4 inches in diameter and in some cases not clearly defined, the impact axis will be taken as coinciding with the nearest transmitter axis A, B or C.

VIBRATION TESTS

9 The transmitter was mounted in an aluminum jig and tested to the vibration specification given in Appendix A. The transmitter output was monitored during the tests.

ELECTRICAL TESTS

10 The electrical tests carried out on the final Phase II transmitters are described briefly below. The following equipment was used to make the tests.

Frequency Counter	Hewlett Packard	5245L
Frequency Counter	" "	52538
Digital Voltmeter	" "	3440A
Vacuum Tube Voltmeter	" "	400 D
Vacuum Tube Voltmeter	" "	410 C
Bolometer	" "	430 C
Signal Generator	" "	651 A
Signal Analyzer	" "	
Receiver and S.D.U.	Communication	
	Electronics	501
Impedance Bridge	General Radio	1608A
V.H.F. Attenuators & Loads	General Radio	
Temperature Chamber,	Calatrol	Model 850
Vibration Equipment	Upton, Brandeed & James	

11 The cases of the transmitters were held at a constant temperature with a thermistor mounted on the surface. Before the tests were started the transmitter was allowed to reach thermal equilibrium at the required test temperature. At this temperature the thermistor was calibrated using a resistance bridge. During the tests the thermistor resistance was maintained at a constant value by adding small quantities of cold gas to the test chamber.

12 Test facilities for checking the electrical specification of the transmitter at 10^{-6} millimeters of mercury at the lower case temperatures were not available. As a result, the transmitter was only tested at a constant case temperature of 60 degrees Celsius under the high vacuum conditions. The case temperature was maintained at a constant value by heating the transmitter with infrared light as required.

13 A schedule of tests to be carried out on the transmitters is given in Table 2. Because of the time required to conduct some of the tests, particularly the warm up time and short term stability, one transmitter was tested at all possible combinations of temperature and supply voltage. It is felt that after the characteristics of one transmitter are completely determined an abbreviated test schedule can be used for the other transmitters.

14 TESTS 1 AND 2, WARM UP TIME AND FREQUENCY VERSUS CASE TEMPERATURE. The measurement of warm up time requires some knowledge of the environment in which the transmitter is warming up. For this reason the warm up time has been measured at a constant case temperature. With this information, plus the case temperatures versus frequency characteristic of the transmitter and knowing the power input, efficiency and thermal properties of the environment, the warm up time can be calculated for each transmitter application.

TEST NO.	TEST DESCRIPTION	SUPPLY VOLTAGE	TRANSMITTER YTX-1-2 SER. X2 CONSTANT CASE TEMPERATURE	TRANSMITTER YTX-1-2, SER. X1, X3 & X4 CONSTANT CASE TEMPERATURE
		V	10^{-6} mm Hg 0°C 25°C 60°C 60°C	0°C 25°C 60°C
1	Warm Up and Short Term Stability	-16.0 -20.0 -24.0	X X X X X X X	X X
2	Frequency versus Temperature	-16.0 -20.0 -24.0		X
3	Frequency versus Supply Volts	-16.0 -20.0 -24.0	X X X X X X X	X X X
4	Power and Efficiency	-16.0 -20.0 -24.0	X X X X X X X	X X X
5				
6	Antenna Loading	-16.0 -20.0 -24.0	X X X X X X X	X X X

Table 2. Schedule of Electrical Environmental Tests (Sheet 1 of 2)

Table 2.

TEST NO.	TEST DESCRIPTION	SUPPLY VOLTAGE	TRANSMITTER YTX-1-2 SER. X2 CONSTANT CASE TEMPERATURE	TRANSMITTER YTX-1-2, SER. X1, X3 & X4 CONSTANT CASE TEMPERATURE
		V	0°C 25°C 60°C	0°C 25°C 60°C
7	Modulation Sensitivity	-16.0 -20.0 -24.0	X X X X X X X X X	X X X
8	Modulation Amplitude Linearity	-16.0 -20.0 -24.0	X X X X X X X X X	X X X
9	Modulation Bandwidth	-16.0 -20.0 -24.0	X X X X X X X X X	X X X
10	Input Impedance	-16.0 -20.0 -24.0	X X X X X X X X X	X X X
11	Spurious r.f. Radiation	-16.0 -20.0 -24.0	X X X X X X X X X	X X X

Table 2. Schedule of Electrical Environmental Tests (Sheet 2 of 2)

Table 2.

15 TEST 6, ANTENNA LOADING. The change in frequency of the transmitter as its load is changed from 50 ohms to a short circuit to an open circuit is a measure of the effect of antenna loading. Open and short circuits represent the worst case. Changes in frequency for loads between open and short circuit will be less than the worst case and will also be dependent on the length of the power output cable.

16 TESTS 7 AND 8, MODULATION SENSITIVITY. Modulation sensitivity and amplitude linearity is measured with an AC input signal and an FM receiver since the short term drift of the transmitter is not zero. Ideally these measurements would be made with DC voltages and a frequency counter but for the drift problem. The biasing arrangement of the modulation circuit is such that the input floats at four volts negative. Shorting the input to ground therefore produces a frequency shift. Modulation linearity is obtained by measuring the demodulated receiver output for several input signal levels.

17 TEST 9, MODULATION BAND WIDTH. The measurement of band width below 10 Hz is limited by the equipment available for the tests. Since the transmitter modulation input is DC coupled the transmitter is assumed to be flat to DC below 10 Hz.

18 TEST 10, INPUT IMPEDANCE. The input Impedance is measured using a DC resistance bridge applied directly to the signal input cable.

SECTION 8

TEST RESULTS

IMPACT TESTS

1 The results of the impact tests are given in Tables 4, 5 and 6 which have been plotted in Figures 22, 23 and 24. Figure 25 shows the impact signatures of a few records which were particularly clean. Table 3 shows the frequency changes (Δf) which occurred for each of these traces.

2 Examination of Figure 25 and Table 3 indicates a definite similarity in the impact pulses for transmitter X3. The frequency increases rapidly for approximately 0.075 millisecond, decays more slowly for approximately 0.25 millisecond and then goes negative for approximately 0.2 millisecond. The two results for transmitter X2 show a slightly different pulse with only a positive frequency change. The reason for the negative change has not been clearly established but it is surmized that it is due to the relaxation of the plastic after impact. The pulse time for all the transmitters appears to be approximately 0.3 millisecond. The positive change has been assumed the more important frequency shift, since the negative one appears to occur after the ball has left the target.

3 In Tables 3, 4, 5 and 6 the primary pulse is taken as the positive change and the secondary pulse is the following negative change. During several impacts there was a small negative pulse before the larger positive one. These pulses appear in the table under the primary pulse only with negative sign. Their origin is unexplained. Figures 22, 23 and 25 are plots of the positive shifts in frequencies for the three transmitters tested. Several trends can be seen. Figures 22 and 24 show a definite decrease in frequency change along the A-axis as the velocity decreases. Several points in Figure 23 indicate that the frequency changes occurring along the B-axis increase with decreasing velocity which is inexplicable. The average frequency changes for transmitter X3 lie between +37 kHz and +118 kHz. Transmitter X3 was the best of the four final transmitters both electrically and mechanically. Its eventual failure after being removed from the test sphere was unfortunate.

4 The impact tests for transmitter X3 into a sand target gave results of zero frequency change for one shot and - 28 kHz for the second shot. (See Table 6). The transmitter was fired horizontally into a box with a mylar window.

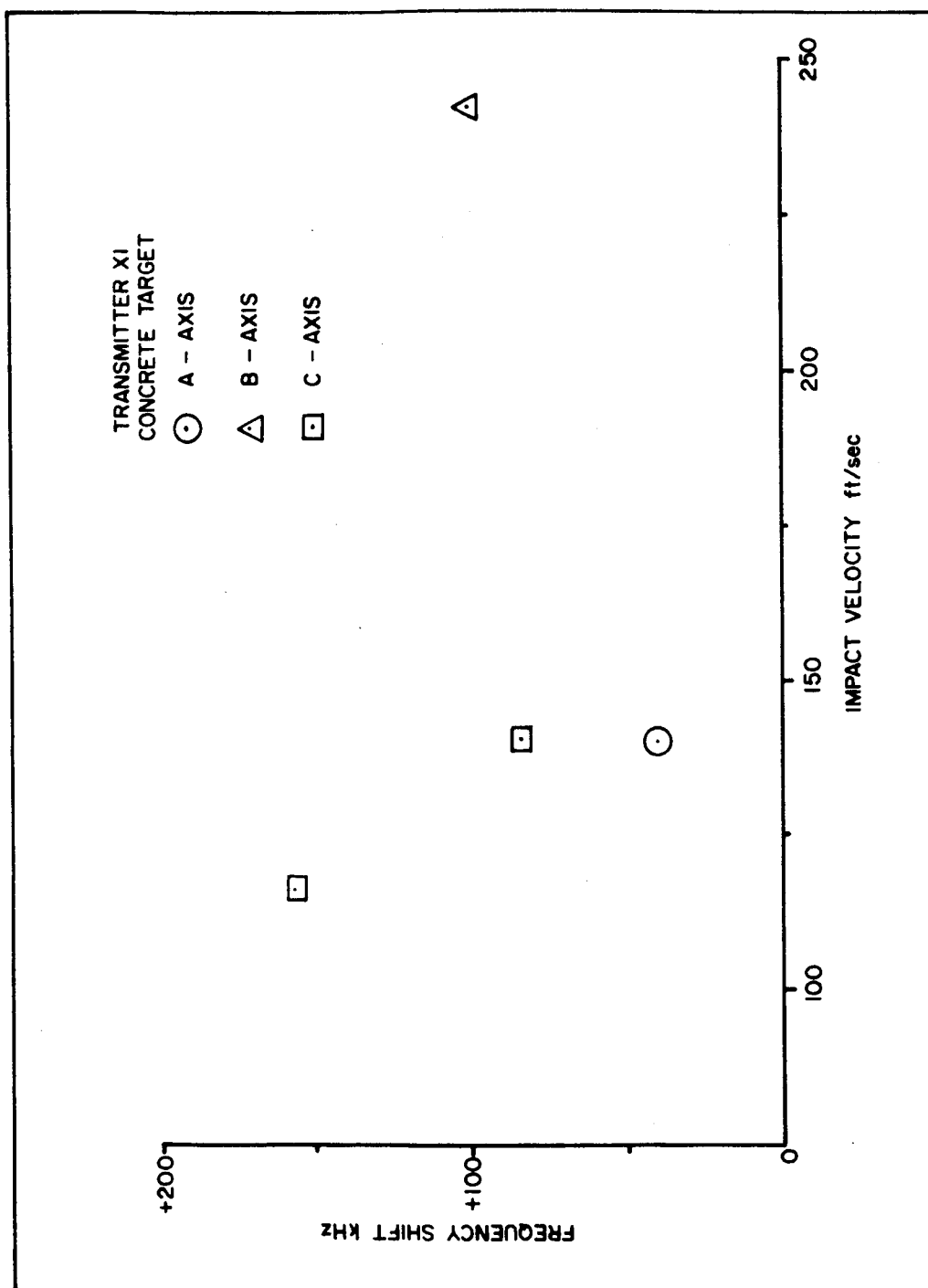


Figure 22. Impact Test Results, Transmitter X1

Figure 22.

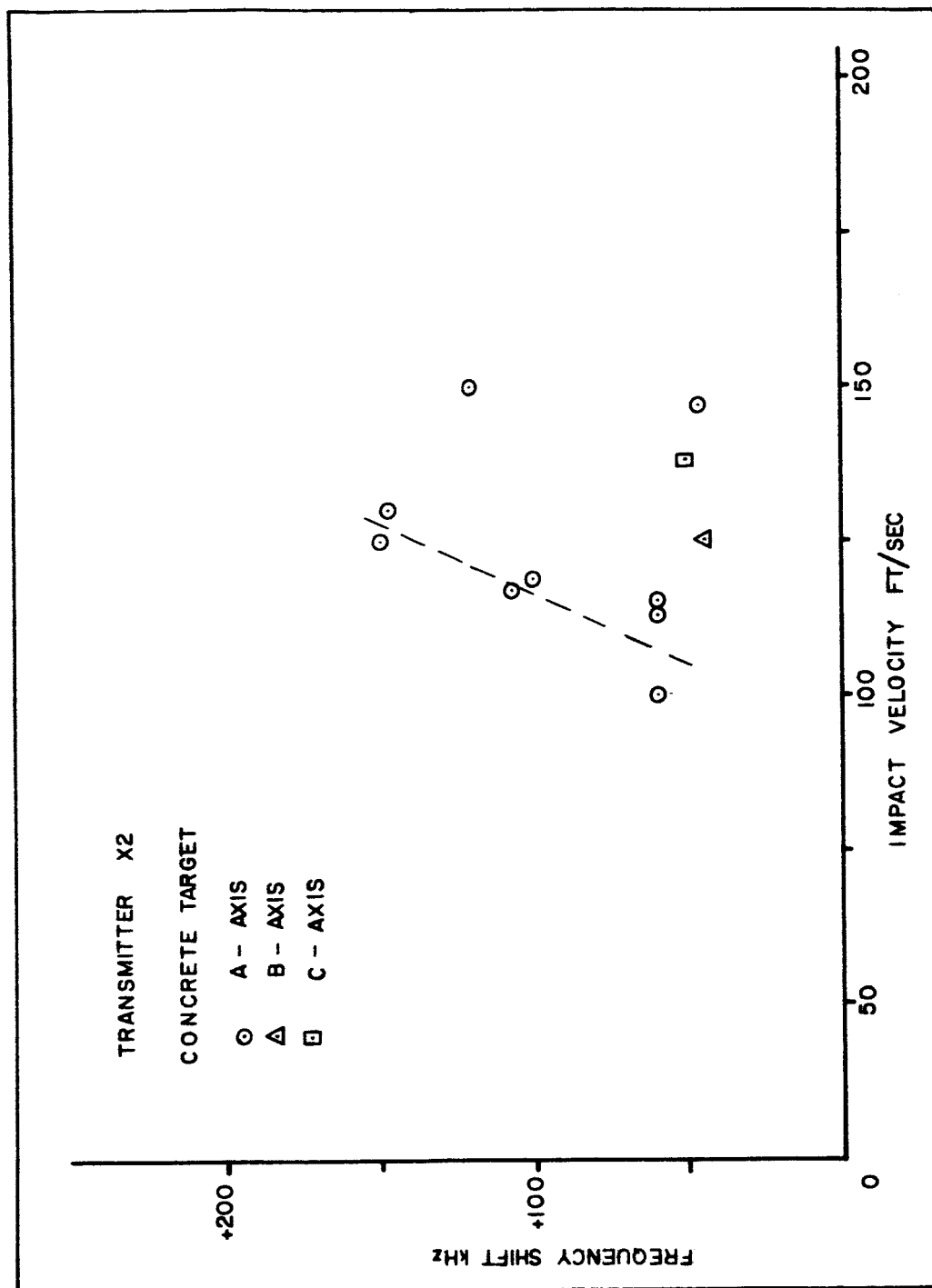


Figure 23. Impact Test Results, Transmitter X2

Figure 23.

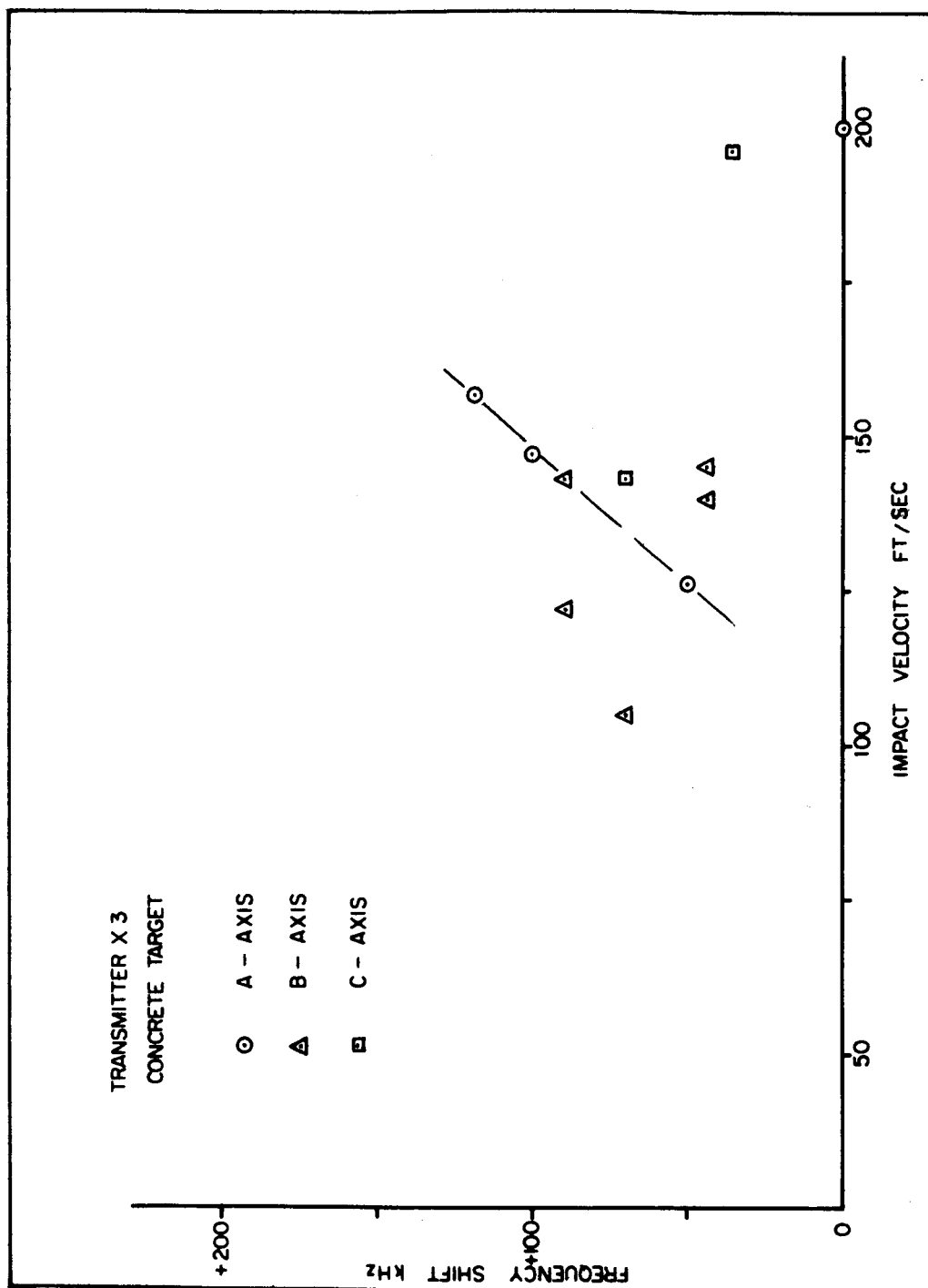
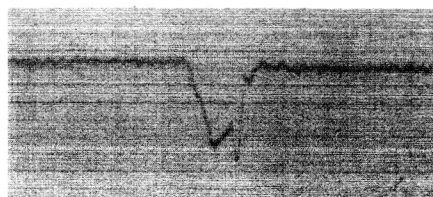
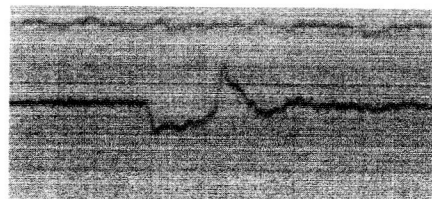


Figure 24. Impact Test Results, Transmitter X3

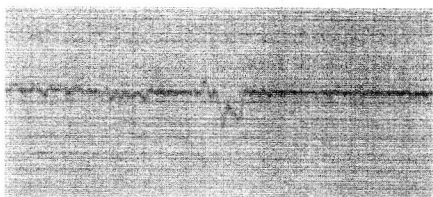
Figure 24.



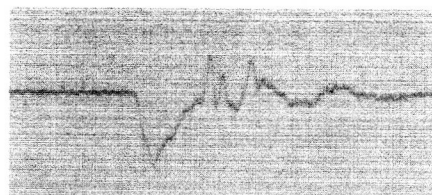
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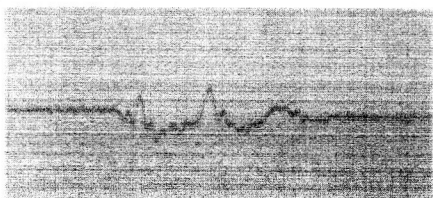
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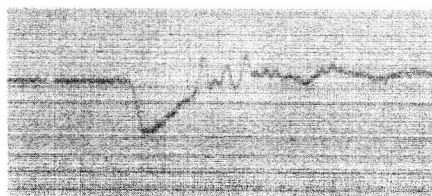
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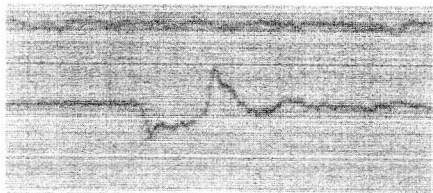
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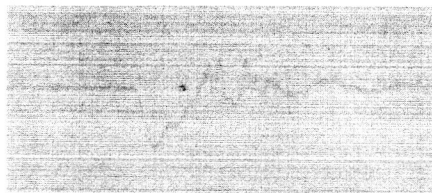
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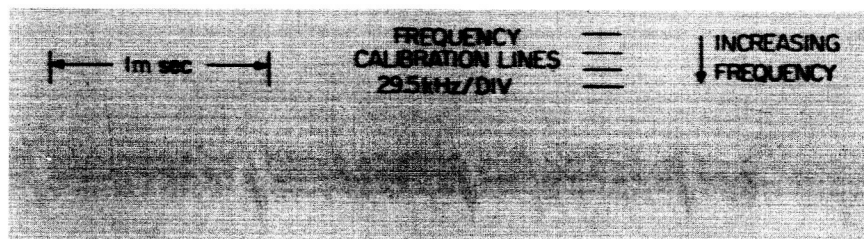
228



222



230



TIMING MARKS

Figure 25. Selected Records Showing Transmitter Frequency Change during Impact

TRANSMITTER	AXIS	SHOT NO.	VELOCITY (ft/sec)	Frequency Change kHz	
				PRIMARY	SECONDARY
X2	A	203	130	+148	0
	B	210	125	-15	+44
X3	A	227	142	+118	-57
	A	230	145	+100	-43
	B	222	140*	+44	-57
	B	223	140	+44	-57
	B	228	142	+90	-43
	C	219	141*	+44	-43
* Approximately					

Table 3. Selected Tape Recorder Results (see Figure 21 and 22)

SUPPLY VOLTAGE = -20V, TEMPERATURE = 25°C ± 5°C				
AXIS	SHOT NO.	VELOCITY (ft/sec)	FREQUENCY CHANGE kHz	
			Primary	Secondary
A	151	-	-	-
A	139	92	-	-
A	191	103	-	-
A	192	227	-	-
A	216	140	+40	-180
B	146	242	+100	-100
B	147	183	-	-
B	148	115	-	-
B	149	110	-	-
B	150	222	-	-
C	141	110	-	-
C	142	136	-	-
C	143	140	+48	-96
C	144	143	-	-
C	145	116	+156	-90
Average			+95	

Table 4. Impact Tests of Transmitter X1 on Concrete Target

SUPPLY VOLTAGE = -20V, TEMPERATURE = 25°C ± 5°C				
AXIS	SHOT NO.	VELOCITY (ft/sec)	FREQUENCY CHANGE kHz	
			Primary	Secondary
A	194	100	+60	
A	195	117	+108	0
A	196	117	-	-
A	197	115	+60	-30
A	198	-	-	-
A	199	113	+60	0
A	200	125	+150	0
A	201	125	-24	+150
A	202	119	+100	0
A	203	130	+148	0
A	204	147	+45	0
A	205	172	-	-
A	206	160	-	-
A	207	150	+110	-40
B	140	115	-	-
B	208	195	-	-
B	209	114	-	-
B	210	125	-15	+44
B	211	-	-	
C	212	120	-	-
C	213	138	+50	0
C	214	128	-135	0
C	215	135	-	-
Average A-Axis			+99	
Average B-Axis			+44	
Average C-Axis			+50 approx	
Average All Axes			+90	

Table 5. Impact Tests of Transmitter X2 on Concrete Target

SUPPLY VOLTAGE = -20V, TEMPERATURE = 25°C ± 5°C				
AXIS	SHOT NO.	VELOCITY (ft/sec)	FREQUENCY CHANGE kHz	
			Primary	Secondary
A	225	126	+50	-120
A	226	155	-	-
A	227	157	+118	-57
A	229	200	0	-25
A	230	147	+100	-43
B	217	105	+70	0
B	221	148	-	-
B	222	140	+44	-57
B	223	145	+44	-57
B	224A	122	+90	-50
B	224B	128	-	-
B	228	143	+90	-43
B	239	142	-	-
B	240	135	-	-
C	218	105	-	-
C	219	141	+44	-43
C	220	132	-	-
C	231	143	-	-
C	233	162	-	-
C	238	142	-	-
C	241	143	-59	+70
C	242	196	-	-
C	243	196	+37	0
Average A-Axis			+90	
Average B-Axis			+70	
Average C-Axis			+50	
Average All Axes			+70	
<u>Impacts Into Sand Target</u>				
C	234	114	-	-
C	235	112	-	-
C	236	114	0	0
C	237	125	-28	0

Table 6. Impact Tests of Transmitter X3 on Concrete Target and Sand Target

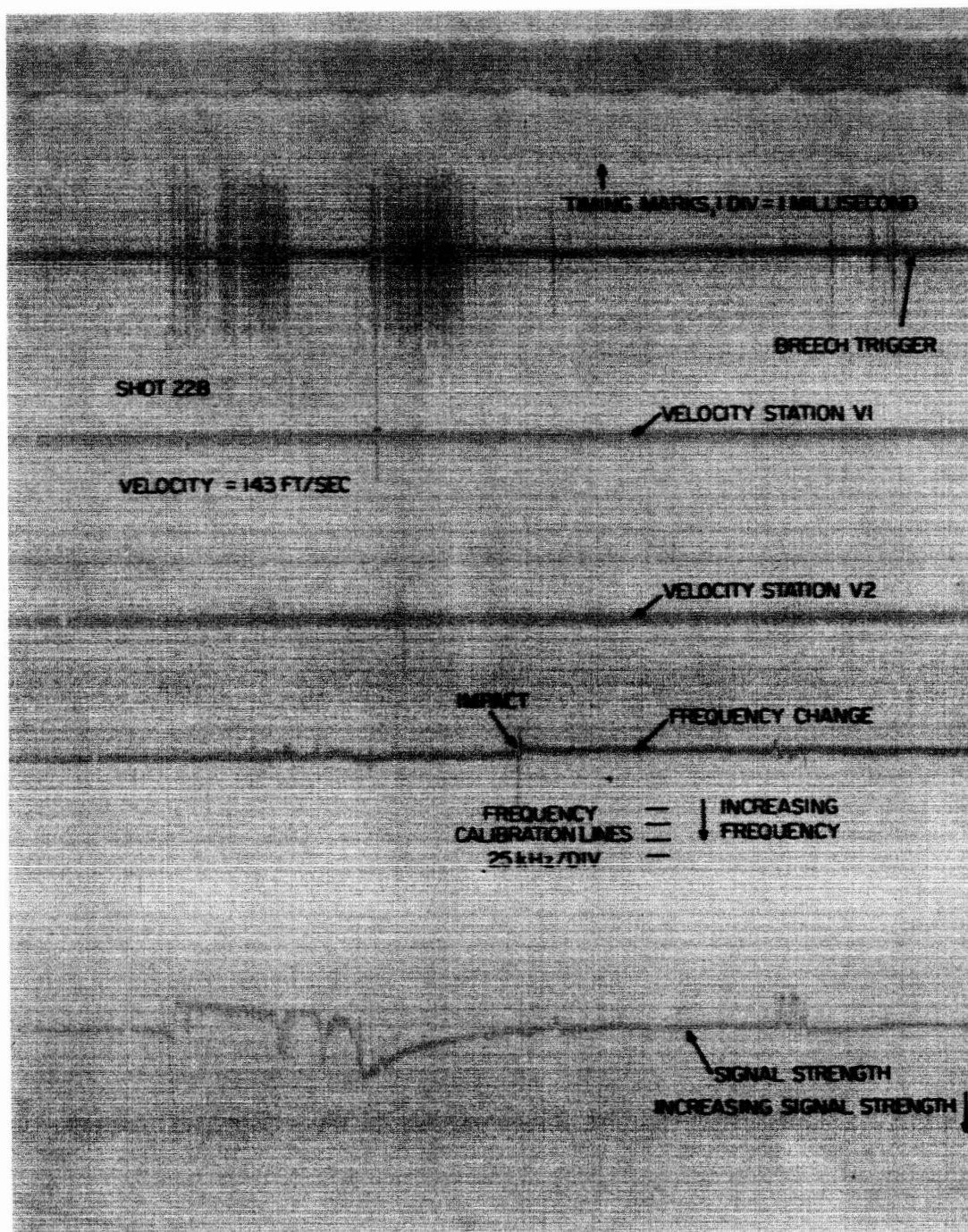


Figure 26. Typical Impact Firing Record, Shot No. 228

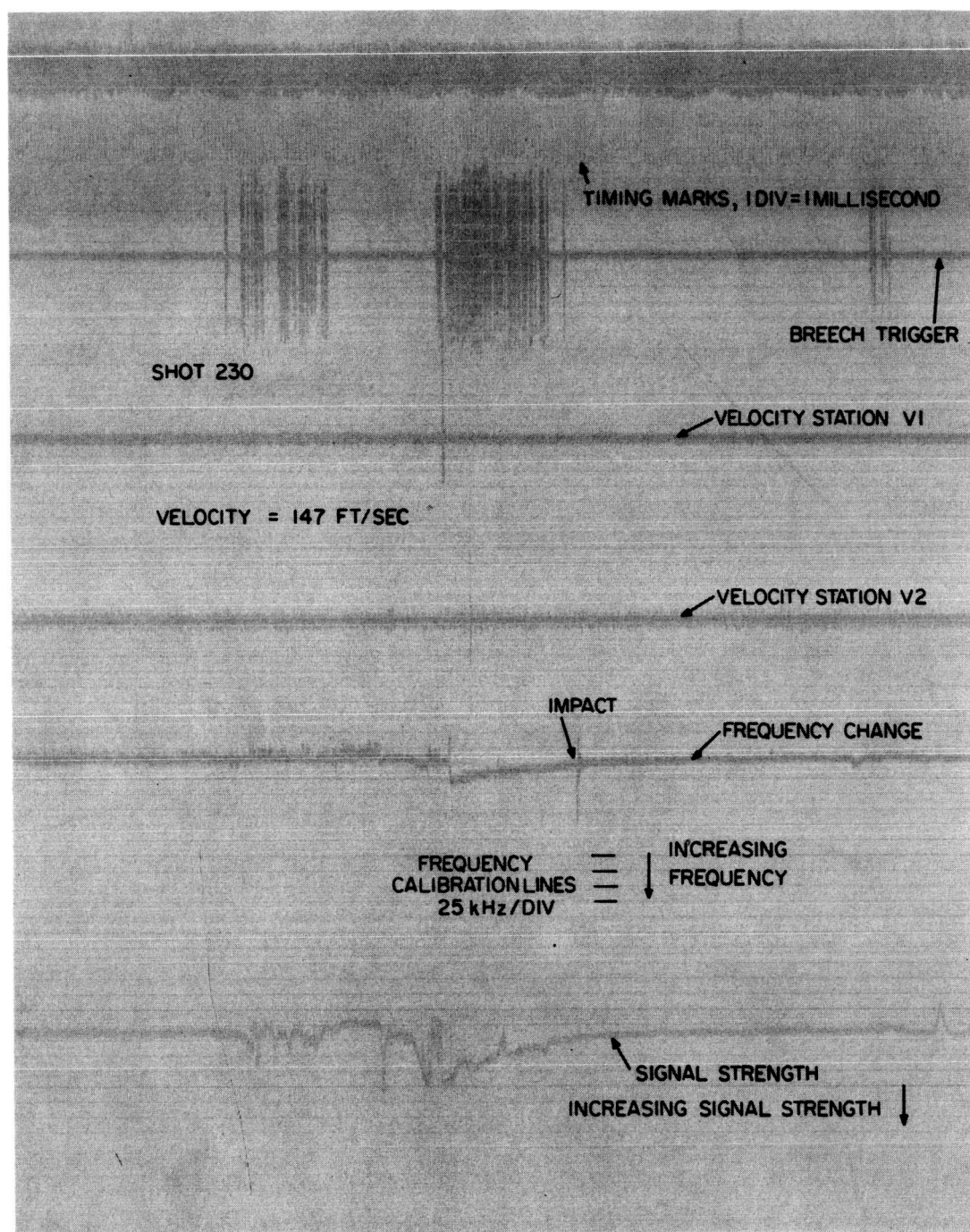


Figure 27. Typical Impact Firing Record, Shot No. 230

TRANSMITTER	SPECIFICATION ±0.07%/VoH	SUPPLY VOLTAGE V	CASE TEMPERATURE		
			0°C	25°C	60°C
X1	±0.640 MHz	-16 -20 -24	+0.409 230.196 MHz -0.249	+0.339 229.339 MHz -0.352	+0.264 228.209 MHz -0.198
X2 Before	±0.680 MHz	-16 -20 -24	+0.321 242.994 MHz -0.022	+0.209 243.056 MHz -0.179	+0.041 243.015 MHz -0.202
X2 Before (Vacuum)	±0.680 MHz	-16 -20 -24			+0.917 243.226 MHz -0.148
X2 After	±0.680	-16 -20 -24	+0.259 243.210 MHz -0.093	+0.091 243.331 MHz -0.187	+0.025 243.213 MHz -0.073
X3	±0.680	-16 -20 -24	-0.042 243.602 MHz +0.029	-0.033 243.530 MHz +0.020	-0.024 243.113 MHz -0.019
X4	±0.680	-16 -20 -24	-0.035 244.707 MHz +0.040	-0.001 244.023 MHz +0.003	-0.018 243.017 MHz +0.009

Table 7. Transmitter Frequency Variation with Supply Voltage

Table 7.

Trans- mitter	Specification ±0.03%	Supply Voltage V	CASE TEMPERATURE					
			0°C	25°C	60°C	0°C	25°C	60°C
			Open Circuit			Short Circuit		
X1	±68 kHz	-400	-400	-350	-325	+500	+300	+150
X2 (be- fore)	±73 kHz	-16 -20 -24 -20 (vac- uum)	+100 -300 -750	+300	+30 +400 +350 +250	-150 -25 +250	250	+25 +50 +50 -300
X2 (after)	±73 kHz	-16 -20 -24	-400 +30 +220	-300 -350 -25	-180 -400 -250	+100 +375 +50	+50 +125 +325	+40 +50 +150
X4	±73 kHz	-20	0	-100	-25	+120	+120	+70
The values given in this table represent the change in frequency, in kHz, as the output load is changed from its normal 50 ohms to open and short circuit conditions.								

Table 8. Antenna Loading

Transmitter	Supply Voltage V	CASE TEMPERATURE		
		0°C	25°C	60°C
X1	-16	43.8	42.5	40.0
	-20	43.2	43.5	42.1
	-24	41.2	42.0	40.6
X2 before	-16	51.3	57.8	49.4
	-20	48.4		51.6
	-24	43.5		58.0
X2 (vacuum) before	-16			48.6
	-20			50.0
	-24			58.5
X2 after	-16	52.8	54.0	50.0
	-20	53.0		52.8
	-24	46.0		50.0
X3	-16		48.0	
	-20		48.0	
	-24		48.0	
X4	-16	41.5	49.5	35.5
	-20			
	-24			

The values of modulation sensitivity in the table are in kHz/volt (the work statement specifies 50 kHz/volt), and are obtained from a measurement of the RMS voltage at the discriminator of the receiver using a calibration factor of 27.8 kHz/volt. The transmitter input is 1 VRMS.

Table 9. Modulation Sensitivity

5 Figures 26 and 27 show typical firing records. The bottom trace in each Figure is the signal strength and it is seen to increase as the ball leaves the barrel and gradually decrease as the ball approaches the target. This decrease is due to the orientation and location of the receiving antenna. Severe random pulses on the frequency change trace and the signal strength record occur before the impact. These are difficult to explain but are probably again due to the receiving antenna orientation and the presence of various metal support structures around the test facility.

6 Considerable difficulty was encountered in obtaining sufficient data shots. It was not until the entire instrumentation system was remodeled to include a multichannel tape recorder that consistent results were obtained. Cable breakage presented another problem which was practically overcome by renewing the cable every two or three shots.

7 It was found that accurate control over the velocity was difficult to maintain. A definite jump in velocity from 150 to over 200 feet per second occurred when the loading pressure of the compressed air launcher was increased from 90 to 95 pounds per square inch. Rather than risk firing the ball at the excessively high velocities the pressure was maintained at 90 pounds per square inch with the resulting range of velocities between 120 and 155 feet per second.

8 Considerable damage to the balls occurred during the test. Both X1 and X2 had to be repaired before testing could be completed. This was done by pressing, as much as possible, the damaged areas of the ball into their original shape and then vacuum potting. The excess plastic was ground away after curing. The repaired balls did not stand up as well but allowed additional tests to be made. The 200 feet per second shots did the most damage.

9 Ball X3 was not too badly damaged during the tests and had only two or three surface cracks. Internally it appeared to be in fairly good condition. Because of the damage to the case of transmitter X3, which was split almost as badly as the case on transmitter X1 shown in Figure 28, it appears that fairly large deflections occur in the fiberglass in the vicinity of the transmitter case. During the impact period the imprint left on the target was measured to be between 1 and 1-1/4 inches in diameter. No measurement of the total deflection of the ball was made. Because of the small size of the impact print and the short pulse time it would appear to be within the specification.

10 All of the transmitters suffered internal failures during the impact tests. Transmitters X2 and X3 failed when the chip transistor in the bias section failed. Tests were continued when it was found that these units operated

satisfactorily at a reduced supply voltage (-13 volts). The power output was reduced considerably but was just adequate for the impact tests. Some difficulty with signal level when the ball was in the barrel was encountered, especially when firing along certain axes, where the transmitter antenna was inside the sabot cup and shielded by the transmitter case. Tests on transmitter X2 terminated when the coaxial cables sheared off where they entered the outer case.

11 The failure of the chip transistors occurred after the first shot for X2 and after 13 shots at less than 157 feet per second followed by one shot at 200 feet per second for transmitter X3. These transmitters were repaired after removal from the ball. The new transistors were coated with silastic and will probably survive additional impact testing. All the cables on X2 had to be replaced at the point where they leave the inner chassis. The inner conductor of the co-axial cables were found to be work hardened and were all very difficult to repair because of this. New lengths of cable were attached but it is felt that on X2 these are a definite weak point. The cables from X3 were in good condition after removal from the ball.

12 After being repaired, transmitter X3 failed on the bench and for no apparent reason. Several things appear to have failed simultaneously. The power output dropped to four milliwatts and the oscillator could only be made to work by shorting the signal input cable.

13 Even then its frequency was 2 MHz lower than normal. The exact cause is not known but it is thought that severe mechanical breakage, similar to that which occurred in X1 caused the failure.

14 Transmitter X1 failed after eight shots below 150 and three shots above 220 feet per second. Figure 28 shows the case of X1 after removal from its test ball. Less damage occurred to the cases of X2 and X3. Calculations based on the Hertz contact laws show that for an impact duration of 0.3 millisecond and a velocity of 140 feet per second the peak acceleration experienced by the ball would be in the order of 130,000 g's, at 240 feet per second the value is 246,000 g's.

15 The transmitters shipped to NASA have been provided with a 1/8 inch wall case which will help considerably in any subsequent testing if the impact velocities are not allowed to greatly exceed 150 feet per second.

16 A careful examination of X1 has been completed and the following conditions were found:

- (a) Of the Corning glass capacitors used, all cracked. One unit was badly shattered.



Figure 28. Photograph Showing Case of Transmitter X1 after Impact Tests

Figure 28.

- (b) One Vitramon capacitor was cracked. It appeared to have had a direct blow as evident from a dent along the side of the transmitter module.
- (c) The resistors, zener diodes, r.f. coils, and temperature compensating capacitors were found to be in good condition.
- (d) The oscillator transistor failed again because of a direct blow.
- (e) Some cracking in the plastic, particularly at partitions, where it was completely pulled away. The partitions could, in fact, be moved slightly between the plastic modules on each side of it. Cracks were visible in the silver r.f. shield.
- (f) All the co-axial cables were sheared off at the outer case.
- (g) All solder connections were good except one around the feed through capacitor, C15.
- (h) The silver r.f. shield remained well bonded to the transmitter module.
- (j) The r.f. chokes cracked but appeared to be in good condition electrically.

ELECTRICAL TEST RESULTS

17 The following Tables and Figures summarize all the results of the electrical tests performed on the four final transmitters. These are discussed in the order they were made. The work statement specifications are given in Appendix A.

18 WARM UP TIME AND SHORT TERM STABILITY. The warm up curves are given in Figures 29 and 30. The warm up time for each transmitter is:

Transmitter X1 - 5 minutes
 Transmitter X2 - less than 1 minute
 Transmitter X3 - 2 minutes
 Transmitter X4 - 4 minutes

Transmitter X2 shows good warm up under all supply voltages and constant case temperature conditions. The warm up of X2 in the epoxy ball at ambient temperature is shown in Figure 29 as curve 5. The warm up time and short term stability are well within those specified in Appendix A. The short term stability for all transmitters is well within the specified ± 0.004 per cent over and five minute period after warm up.

19 Comparing the warm up times in paragraph 18 above to the frequency versus temperature curves given in Figure 31 the warm up time is seen to be dependent on the temperature compensation characteristics of the transmitters. The better the temperature compensation the shorter the warm up time.

20 Exact temperature compensation is difficult to obtain because of the limited selection of values and temperature coefficients of the temperature compensating capacitors and because of the somewhat unpredictable changes in overall temperature compensation which occurred when the transmitter was potted. The lack of adjustable trimmer capacitors has also made exact temperature compensation difficult to achieve. Figure 30 shows that good temperature compensation is possible and with more uniformity in components, the stability achieved in X2 could be reached in all the transmitters.

21 Table 7 shows the variation of the transmitter frequency with supply voltage. These results are also shown for a case temperature of 25 degrees Celsius in Figure 32. All the results are well within the specified limits of 0.07 per cent per volt for supply voltage changes of ± 20 per cent.

22 Figures 33 and 34 give the power output and efficiency curves at various supply voltages and constant case temperatures. The power outputs for transmitters X1, X2 and X3 are somewhat below 100 milliwatts at the low supply voltage. The impact tests on transmitter X2 appeared to have lowered its output somewhat. The output of X4 is very low, especially at the lowest supply voltage and the higher temperatures. The efficiencies for all the transmitters, except X4, were generally above the required 15 per cent.

23 The power output and hence efficiency depend on the tuning of the r.f. circuits in the transmitter. The tuning in turn is very dependent on the potting plastic and its effect on the stray capacitance in the circuit. Generally by potting each stage one at a time the required power output, efficiency and buffering can be obtained. The low output power of X4 is due to difficulties which were encountered during the potting and which would have required the transmitter to have been partially rebuilt to increase the power. Insufficient time was available to do this.

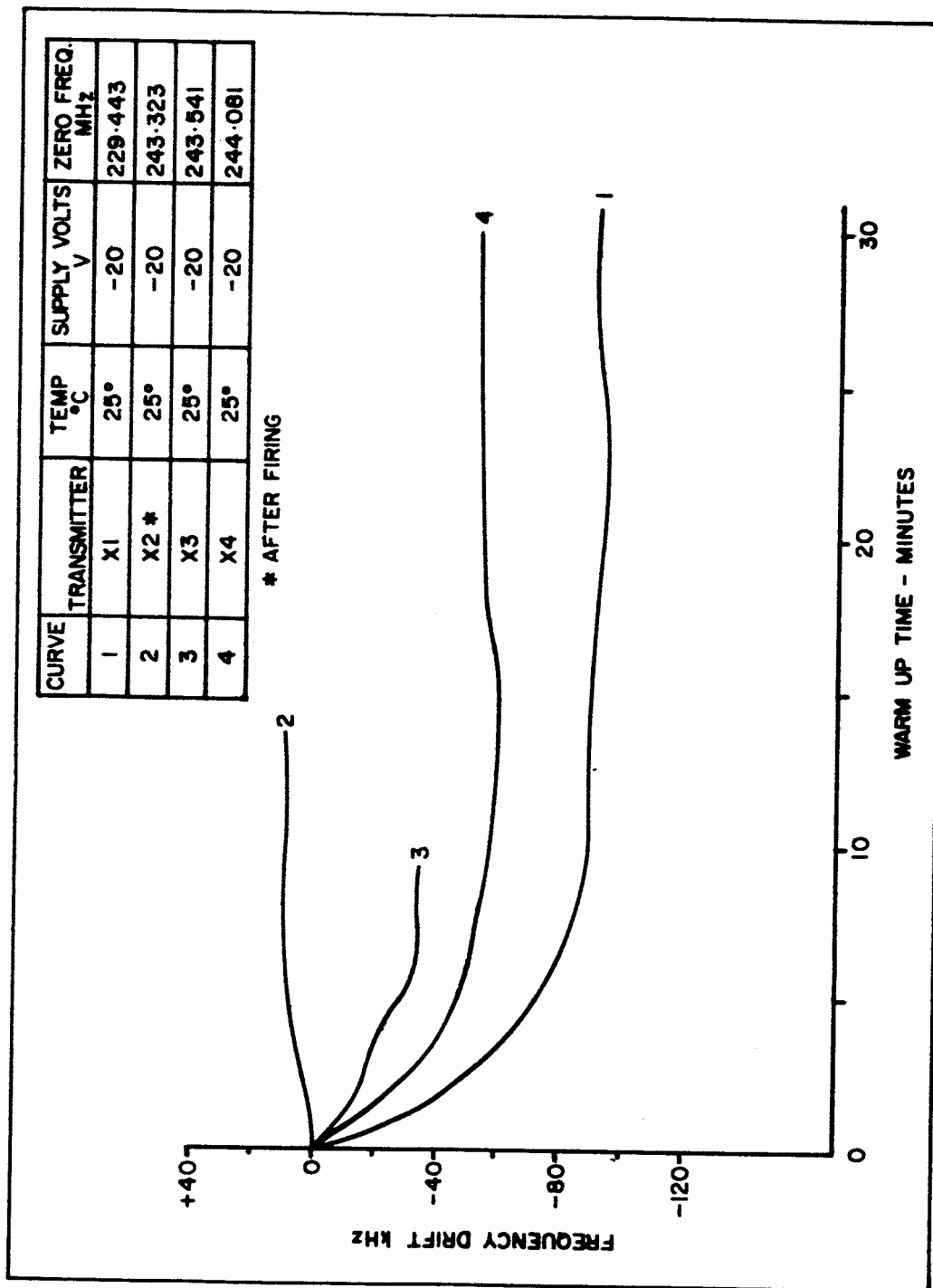


Figure 29. Transmitter Warm Up Times and Short Term Stability

Figure 29.

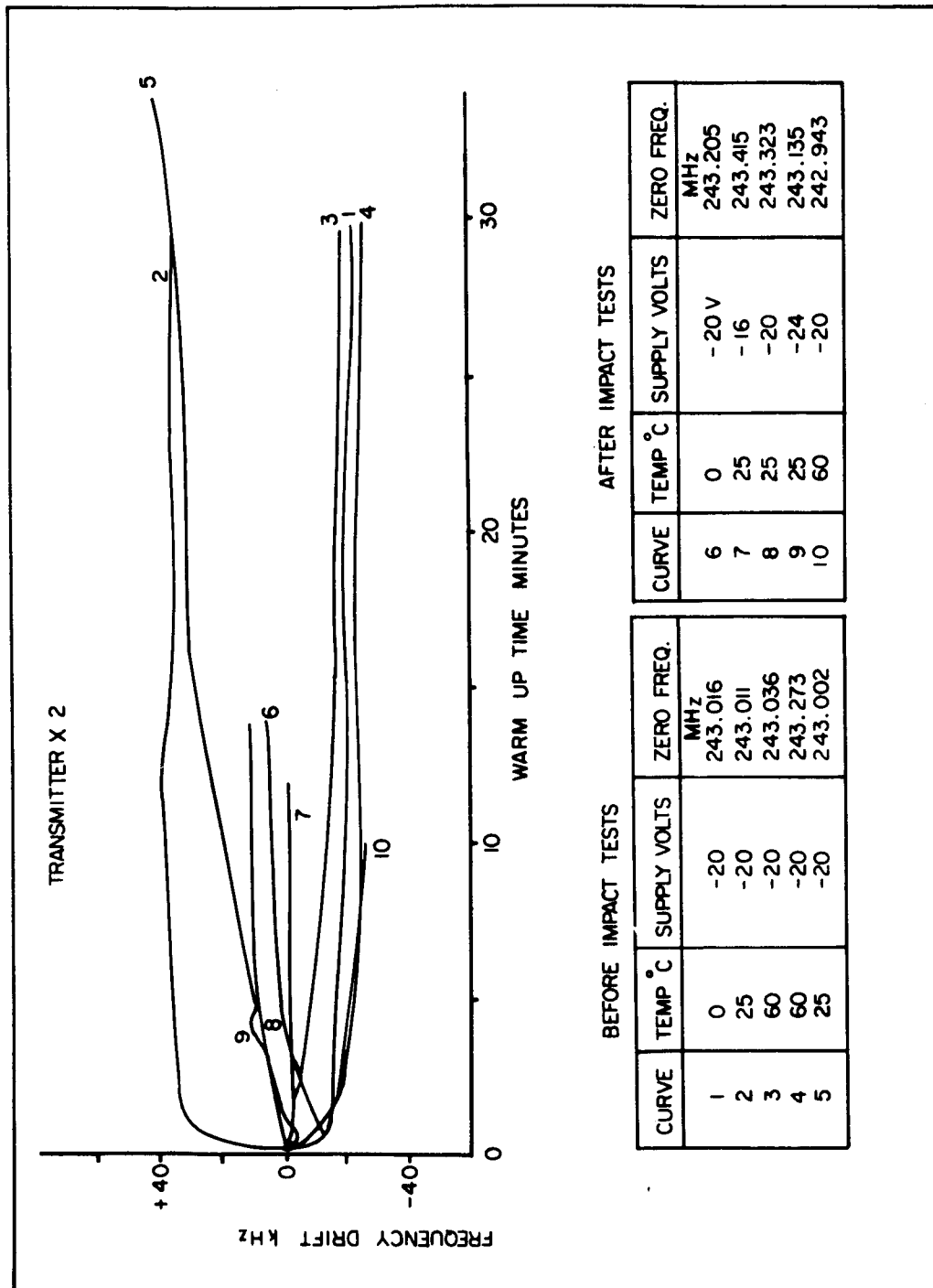


Figure 30.

Figure 30. Transmitter X2 Warm Up Time and Short Term Stability

Temperature °C	Modulation Input Voltage 1 kHz Peak to Peak Volts	Suppl
		-16V
0	5.0	43.6
	2.8	
	2.5	
	1.4	
	0.5	
	0.28	
	0.25	
	0.14	
	0.05	
25	5.0	42.4
	2.8	
	2.5	
	1.4	
	0.5	
	0.28	
	0.25	
	0.14	
	0.05	
60	5.0	39.8
	2.8	
	2.5	
	1.4	
	0.5	
	0.28	
	0.25	
	0.14	
	0.05	

Table 10.

Modulation Sensitivity (kHz)											
X1 Before (Vacuum)			X2 After			X3			X4		
Supply Voltage			Supply Voltage			Supply Voltage			Supply Voltage		
6V	-20V	-24V	-16V	-20V	-24V	-16V	-20V	-24V	-16V	-20V	-24V
			52.8	52.5 53.4 52.5	45.8					41.2	
				54 53.1 54							
			50.6	52.5 54.5 54.0	56.2	47.8	47.8	47.8		39.6 40.6 49.4	
				55.5 54.5 55.5						40.4 43.2	
3.6	50 50 52.8 61.2 64	58.4	50.1	49.4 52.8 50.9 50.9 51.2 50.9	50.1					35.6	

Table 10. Modulation Linearity

24 The effect of open and short circuit loads on the transmitter frequency is given in Table 8. It is seen that transmitter X4 has the best buffering. This is because the power output is low.

25 The electrical tests for transmitter X3 were not completed before the impact tests performed on it and it failed before the electrical tests could be completed after its removal from the epoxy ball. The tests that were performed before the impact tests demonstrated that besides having adequate power its buffering and modulation characteristics were very good.

26 The modulation sensitivity for the final Phase II transmitters is given in Table 9. The modulation sensitivity although adjusted with the resistors R2 and R3 is dependent on the r.f. stability in the transmitter. Transmitter X3 is seen to have the best modulation sensitivity characteristics at one temperature. An error in the calibration of the receiver caused the sensitivity for this unit to be 48.0 kHz per volt rather than 50 kHz per volt.

27 Table 10 gives the modulation linearity in terms of the average modulation sensitivity for a number of input voltages. The tabulated figures are calculated by dividing the frequency deviation for a given input voltage by the input voltage.

28 The modulation sensitivity of the transmitter could be increased considerably by lowering the input impedance or by modifying the design of the modulation circuit. Modulation sensitivities of several hundred kHz per volt could probably be obtained without difficulty.

29 The bandwidth characteristics of the final Phase II transmitter are given in Figure 35. This curve is typical of all the transmitters. In order to obtain the low frequency response required, the input stages were D.C. coupled. The response is flat to D.C.

30 The input impedance of the final Phase II transmitters is given in Table 11 below. The input impedance of X2 was lowered to regain the modulation sensitivity which was lost when the chip transistor was replaced after the impact tests.

Transmitter	Temperature °C	Input Impedance
X2	25	76 kΩ
X3	25	140 kΩ
X4	25	82 kΩ
Work Statement Specification; > 100 kΩ		

Table 11. Input Impedance

31 The input impedance before impact testing was 110 kilohms. Transmitter X4 is low because the input impedance was not measured before potting and it would have required considerable rebuilding to make it 100 kilohms.

32 The spurious harmonic distortion was measured for transmitters X2 and X4 and is given in Table 12 below.

Transmitter	2nd Harmonic	Other Harmonics *
X2	-23 dB	> -40 dB
X4	-24 dB	> -40 dB
* There was essentially no third harmonic distortion.		

Table 12. Spurious Harmonic Distortion

The rather high second harmonic distortion is due to the effect of potting and transmitter tuning.

VIBRATION TESTS

33 The vibration tests were carried out according to the requirements given in the Transmitter Specification, Appendix A of this report. The transmitter output was monitored during the test and except for very small frequency shifts (approximately 500 Hz) attributed to the coaxial cables and which were eliminated by taping the cables to the vibrator table, no shifts in frequency were noted.

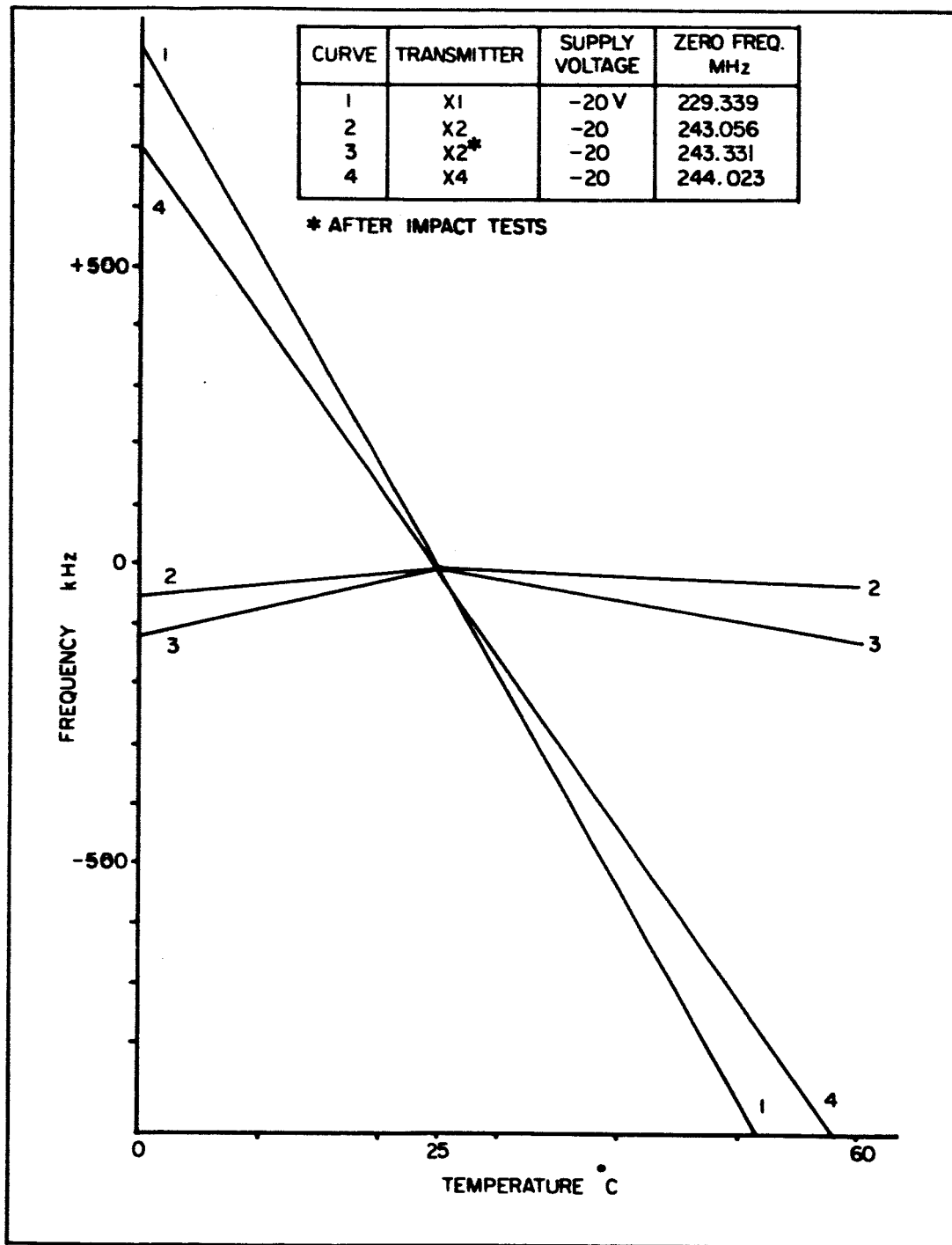


Figure 31. Frequency versus Case Temperature for the Final Phase II Transmitters

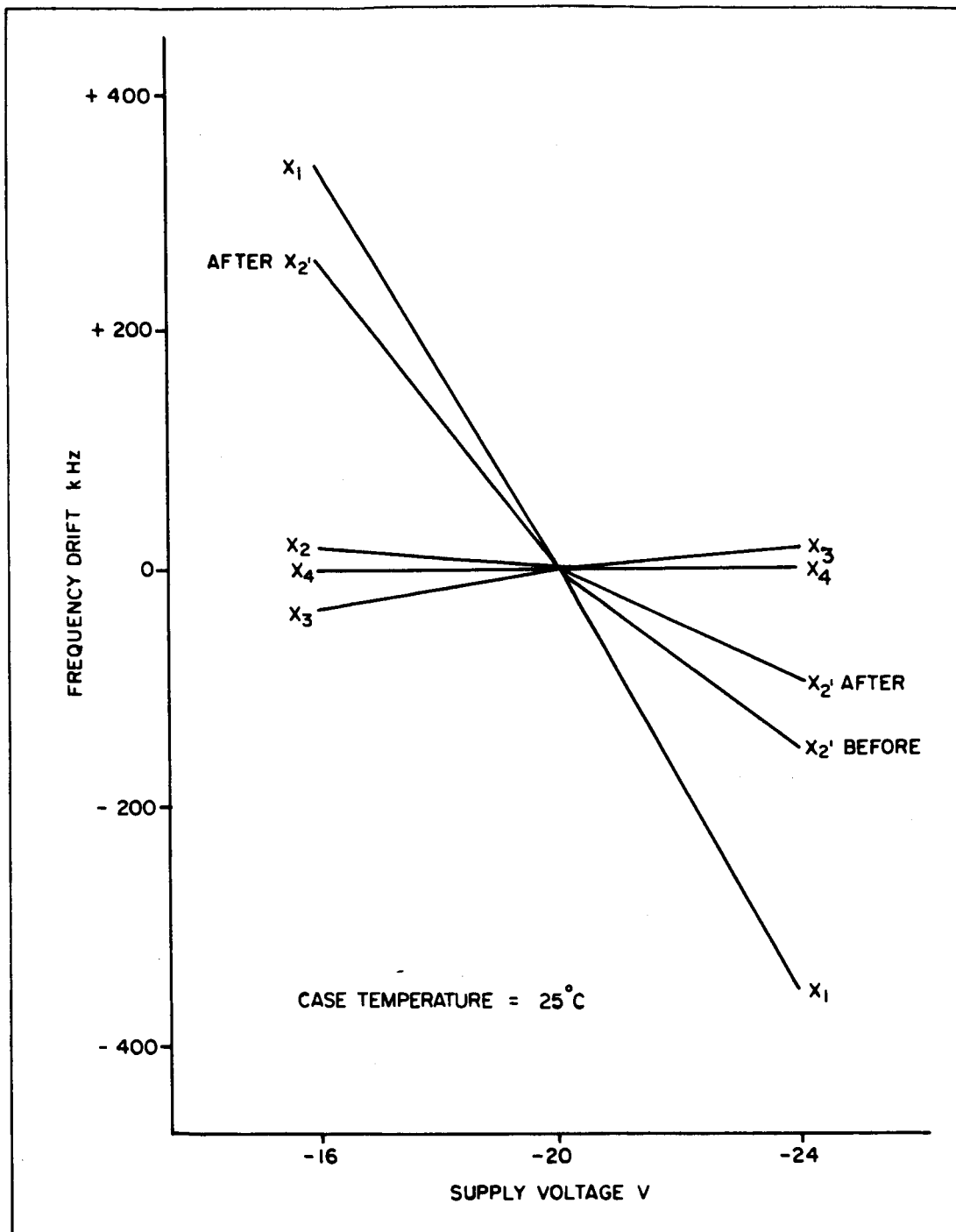


Figure 32. Frequency versus Supply Voltage for the Final Phase II Transmitters

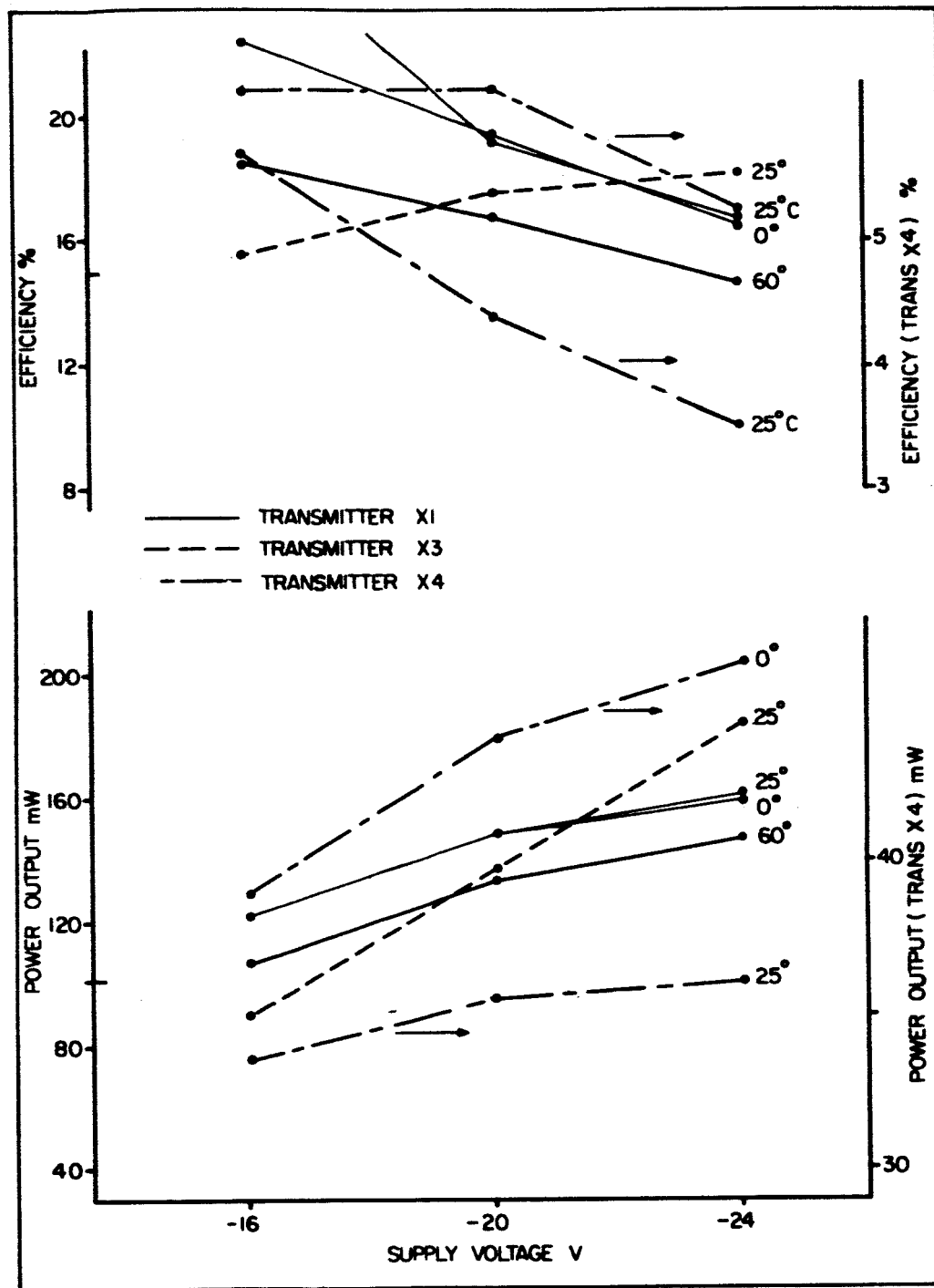


Figure 33. Power and Efficiency Curves for Transmitters X1, X3 and X4

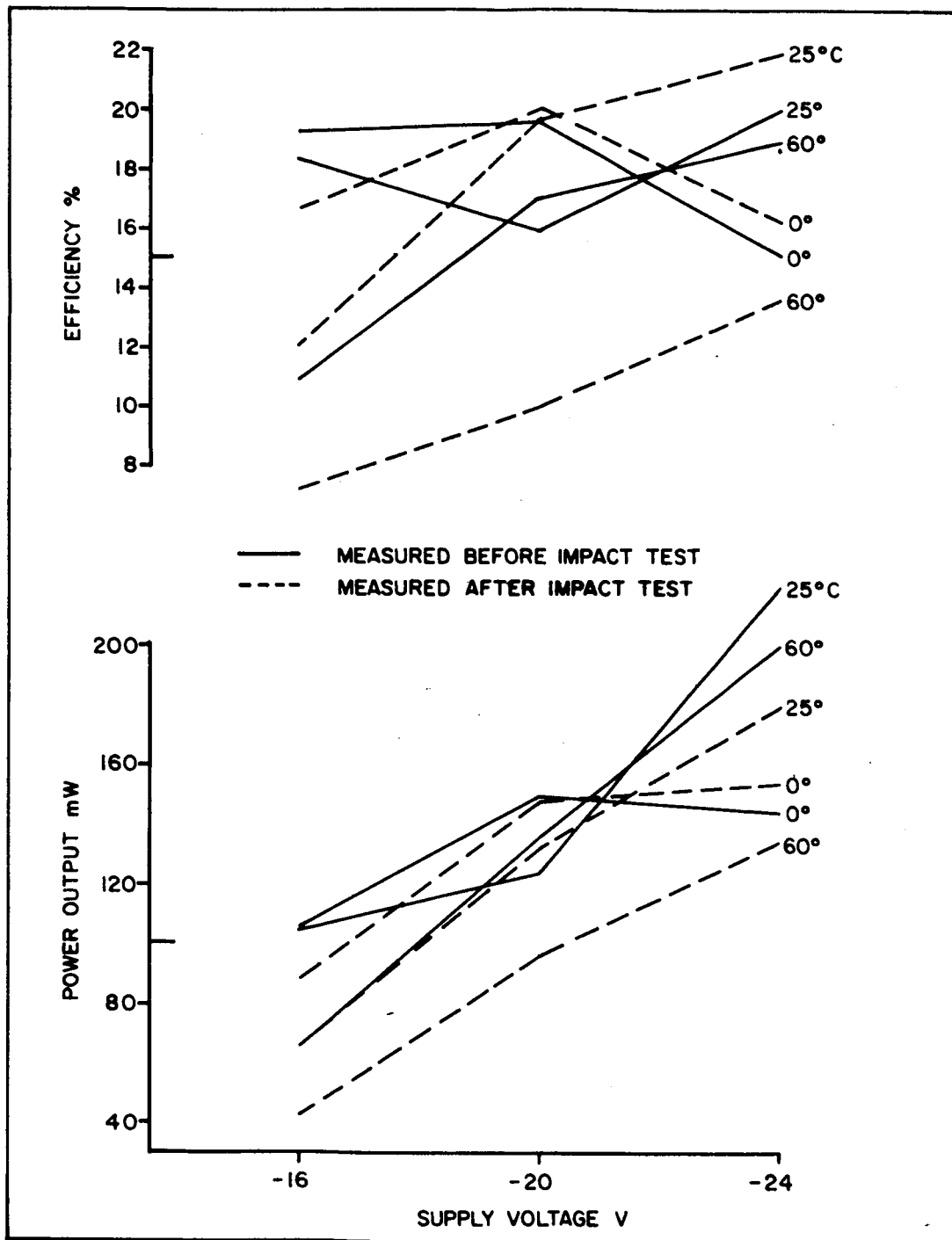


Figure 34. Power and Efficiency Curves for Transmitter X2

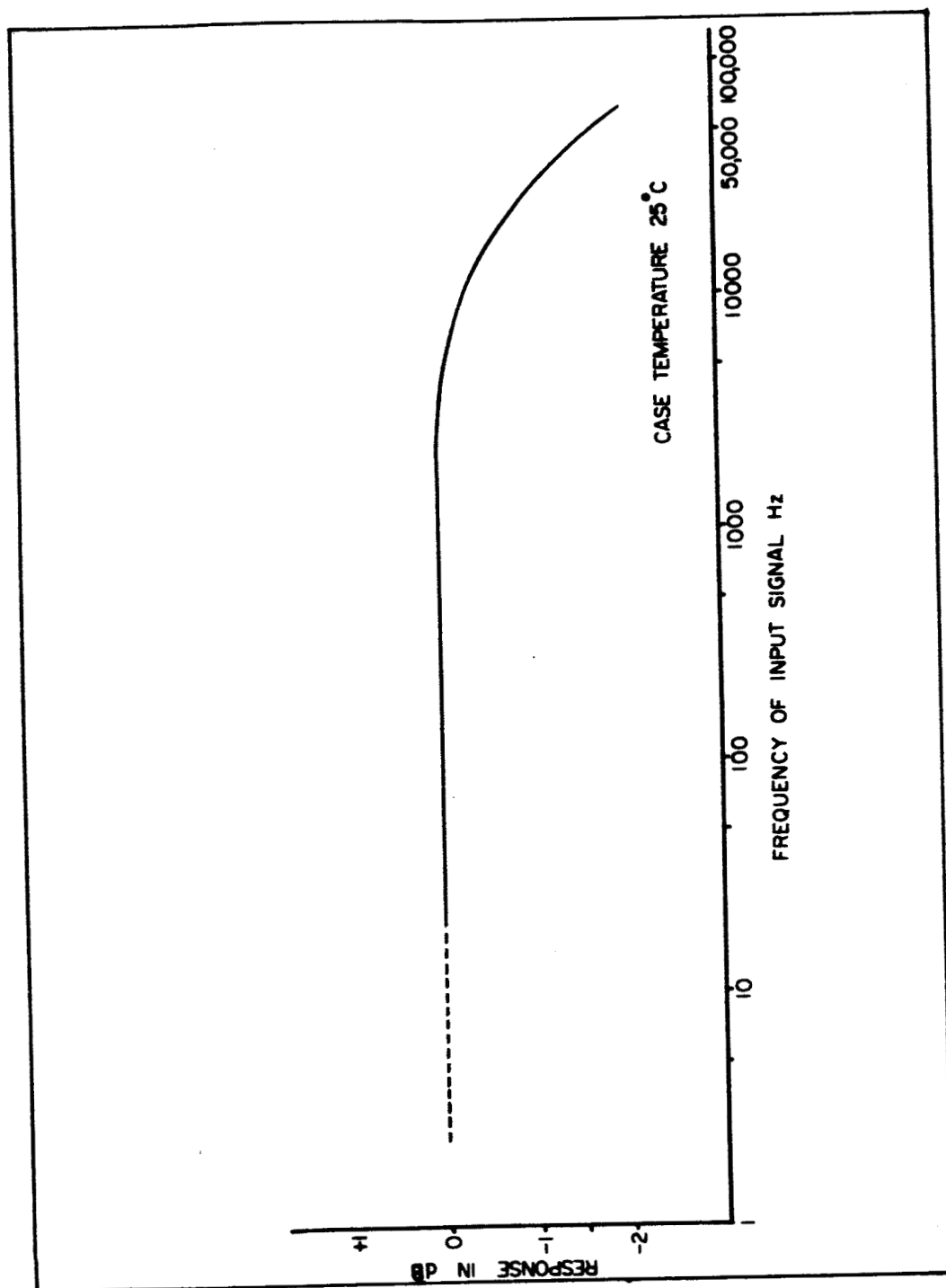


Figure 35. Typical Modulation Bandwidth Curve for the Final Phase II Transmitters

Figure 35.

SECTION 9

CONCLUSIONS

1 The results of the impact tests on three transmitters can be summarized as follows:

- (a) Frequency shifts between +33 and +120 kHz can be expected for impacts along any axis at velocities between 100 and 150 feet per second. For velocities below 100 feet per second the frequency shifts will probably be much lower and more in line with the work statement requirement.
- (b) A positive shift in frequency lasting 0.3 millisecond occurs during impact followed in some cases by a negative shift of shorter duration and generally lower amplitude.
- (c) A definite velocity dependence along the cylindrical axis is apparent from the test results and an axis dependence is also evident. This axis dependence on load was also noted during the compression tests.
- (d) Not all the components used to construct the transmitter are suitable for this test environment.

2 The damage to the transmitter during the impact tests was considerably greater than had been expected. The complete failure of the cases and the damage to the components and plastic module indicates that additional design work and testing will be required to improve the present performance of the High Shock FM Transmitter YTX-1-2. The fact that a correlation between the compression tests and the impact tests on the final transmitter was found would aid considerably in the design of future transmitters.

3 Aside from further component tests, particularly of adjustable trimmer capacitors and thin film circuits, a much stronger chassis would be required to provide support and reduce the load on each section of the transmitter. Additional stress relief would be beneficial. Examination of transmitter X1 indicated that the inner module was actually dented during one of the shots. Increasing the strength of the chassis and case would bring about an increase in size and weight. This could be offset somewhat by using thin film circuits or similar techniques.

4 Electrically the transmitter is capable of meeting all of the electrical specifications. The failure of transmitter X3, before the completion of the electrical tests on it, was unfortunate because tests carried out on this unit during its construction indicated that it had excellent characteristics. The

tests which were completed, bear this out. The frequency shifts measured for this unit during the impact tests were generally lower than for the other two transmitters.

5 The lack of a suitable trimmer capacitor has made the tuning of the transmitter a difficult and rather slow process. It is felt, however, that had two or three additional transmitters been built, the problems involved in assembling and tuning the transmitters with fixed trimmer capacitors would have been overcome and the electrical characteristics would have been uniform and very close to the work statement specification.

6 Considering the very high g levels and the severity of the repeated testing at these g levels the frequency stability of the transmitter during the impacts was very high. Considerable additional effort would be required to significantly improve the performance of the final Phase II High Shock FM Transmitter.

APPENDIX A

TRANSMITTER SPECIFICATION

1 The following specification is taken from the work statement of NASA project NAS1-5042. This is included in this report to provide quick reference to the design objectives for the High Shock FM Transmitter.

TRANSMITTER SPECIFICATION

2 ELECTRICAL.

- (a) POWER OUTPUT. Shall be a minimum of 100 milliwatts into a 50 ohm resistive load.
- (b) OUTPUT IMPEDANCE. Shall be 50 ohms nominal.
- (c) FREQUENCY. Any single fixed frequency in the 240 to 245 MHz band.
- (d) WARM-UP TIME. Shall not exceed one (1) minute.
- (e) SHORT-TERM FREQUENCY STABILITY. Shall be within plus or minus 0.004 per cent during any 5-minute interval after warm-up.
- (f) SHOCK. The carrier center frequency shall not vary more than plus or minus 0.004 per cent when the transmitter, packaged in a reinforced 3-1/2 inch plus or minus 1/2 inch spherical epoxy ball, is impacted upon hard concrete targets at one-hundred and fifty (150) feet/second. The FM products generated during this level of shock shall not exceed plus or minus ten (10) kHz.
- (g) LOADING. Frequency shall not vary more than plus or minus 0.03 per cent from the frequency of operation into a 50 ohm resistive load if the r.f. output is open or short circuited.
- (h) VOLTAGE. Frequency shall not vary more than plus or minus 0.07 per cent per volt for supply voltage variations of plus or minus 20 per cent.
- (j) MODULATION. Shall be FM.

- (k) BANDWIDTH. Shall be from 5 Hz to 10,000 Hz and shall be linear to within 5 per cent from 25 Hz to and including 4,000 Hz.
- (m) MODULATION SENSITIVITY. Shall be 50 kHz/volt plus or minus 1 kHz for a maximum excursion of 250 kHz (input signal level 0 to 5 volts).
- (n) INPUT IMPEDANCE. Shall be 100,000 ohms minimum.
- (p) EFFICIENCY. Shall be 15 per cent minimum.
- (q) SUPPLY VOLTAGE. Shall be plus or minus 20 per cent from minus 15 to minus 22 vdc.
- (r) SPURIOUS RADIATION. Spurious radiations shall be 40 dB below the power level of the fundamental.

3 PHYSICAL.

- (a) FORM. Transmitter package shall be of a cylindrical shape with a maximum diameter of 1.50 inches and a maximum height of 1.00 inches.
- (b) MAXIMUM WEIGHT. Two ounces total per unit including encapsulation, metal case, and leads.
- (c) CONNECTIONS. All output and input connections shall be miniature coaxial cable of 1/8 inch maximum O.D. and shall be capable of being soldered. The leads shall extend at least 3 inches external to the transmitter.

4 ENVIRONMENTAL.

- (a) TEMPERATURE. Transmitter shall have capability of meeting all specifications while in continuous operation over the range of 0°C to 60°C in a vacuum of 10^{-6} millimeters of mercury with no heat sink attached external to the transmitter (shock and vibration test not included).
- (b) VIBRATION. Performance shall be unaffected by sinusoidal vibrations according to the following schedule:

5 to	10 Hz	1 inch D.A.)	1/2 octave per minute
10 to	55 Hz	34 i.p.s.)	
55 to	2,000 Hz	30 G	1 octave per minute

- (c) SHOCK. The transmitter outlined in this specification will be employed in an impact measuring instrument package which transmits its deceleration versus time signature when impacted upon various materials.

The instrument, and hence the transmitter, must be capable of transmitting modulation information during shock levels created by impacting the instrument upon hard concrete targets at impact velocities of one-hundred and fifty (150) feet per second. For shock tests only, the transmitter shall be packaged in a 3-1/2 inch \pm 1/2 inch diameter sphere of solid epoxy reinforced with fibreglass rovings or filament windings. During the shock tests, in which the sphere will undergo impacts up to one-hundred and fifty (150) feet per second on hard concrete targets, the deformation of the spherical structure shall not exceed 1/8 inch in any direction. For shock test purposes, the packaged transmitter shall be impacted upon hard concrete targets at velocities increasing from fifty (50) feet per second to one-hundred and fifty (150) feet per second at fifty (50) feet per second intervals; i.e. 50 fps, 100 fps, 150 fps. The instantaneous carrier frequency deviation due to impact shocks shall be monitored during each impact. The maximum spurious FM products allowed are plus or minus ten (10) kHz. The transmitter shall be capable of surviving and meeting the specifications listed herein after being impacted on hard concrete at least twenty (20) times at the 150 fps velocity. In addition, the transmitter performance during impact into 00 masonry sand at 100 fps shall be monitored and test results obtained. The transmitter shall be capable of meeting these shock specifications regardless of its orientation with respect to the acceleration vector, i.e., the transmitter shall not have preferred direction for shock resistance.

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